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TROPOSCATTER ANTENNA POSITIONER

University of Wisconsin

W. P. Birkemeier
A. B. Fontaine

TROPOSCATTER ANTENNA POSITIONER

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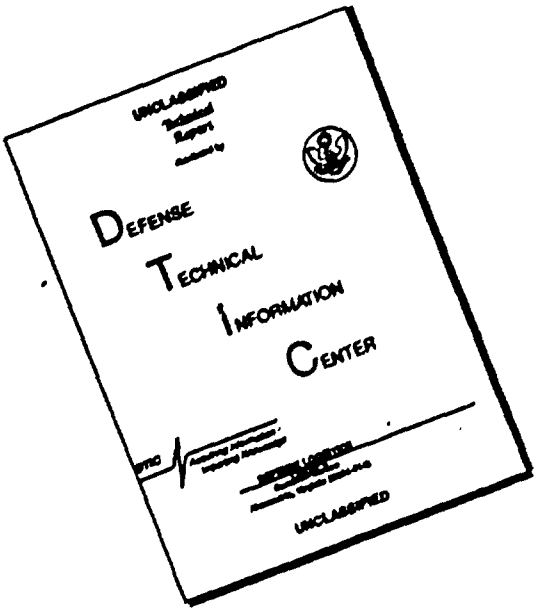
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APPROVED: Paul Sierak

PAUL SIERAK
Project Engineer

APPROVED: Fred I Diamond

FRED I. DIAMOND, Technical Director
Communications and Control Division

FOR THE COMMANDER: John P. Huss

JOHN P. HUSS
Acting Chief, Plans Office

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This report covers results of a contract to provide for a rapid and accurate alignment procedure of troposcatter antennas. An experimental model embodying a micro-processor based computation routine at the receive antenna and a stable transmitted frequency allows for alignment of antennas along the great circle path. The test data shows that an alignment accuracy of better than ± 1/3 degree or approximately ± 1/10 of a beamwidth could be accomplished in approximately 10 minutes.

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ABSTRACT

Under a previous effort "Antenna Alignment Study," F30602-74-C-0276, a technique was formulated to align troposcatter antennas by swinging the beams while noting the symmetry of the received Doppler spectrum. The measure of symmetry was computed from the cross-correlation of the quadrature components of the received complex envelope signal. A concern in this study was the need for synchronization of the transmitter and receiver clocks. This report details the computation of the Doppler spectrum skew which is fairly insensitive to clock offset. A microprocessor was designed and programmed to provide a real-time skew estimate that could be used as an alignment indicator. Tests on the RADC Verona-Ontario link employing TRC-97 radios showed that alignment accuracy better than $\pm$ 1/3° or approximately $\pm$ 1/10 beam-width could be accomplished in about 10 minutes. It was found necessary to set the average frequency shift equal to zero by adjusting the receiver clock in order to estimate spectrum skew corrently using the algorithm presented here.

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Program Name	Description	Pages for FORTRAM Program	Pages for 8085 Program
MAIN	1) Input data (from tape if FORTRAN; A/D or PROM in 8085 2) Pass x,y data samples to other routines PROCESS, DISPLAY, UPDATE, etc.	B.2-3	B.17-18
PROCES	Process an xy data sample and accumulate averages for 1 sec. Includes: 1) Test of xy data sample for minimum signal value 2) Derivative calculations $\dot{x},\dot{y},\ddot{x},\ddot{y}$ 3) One second averages for correlation, skew, and slope variables	B.4-6	B.59-65
DISPLAY	Convert long-term average of correlation, skew, and slope variables to a form suitable for display	B.6-7	B.26-29
INITIAL	Initialize all system variables and parameters	B.7-8	B.23
UPDATE	Add one second averages fo alignment variables formed in the routine PROCES to long-term averages	B.8-11	B.66-72
STARTUP	Program begins here after a manual reset ..	N.A. (not applicable)	B.57-59
ASCHED	Schedules 8085 routines: A/D every 1/100 sec. Front panel scan every 1/10 sec. Display update every sec.	N.A.	B.18
RDFRNT	Scan front panel switches	N.A.	B.19
ATOD	Input analog data	N.A.	B.20-23
DISBCD	Convert a floating point number to BCD format and display it	N.A.	B.23-26
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Evaluation

This report summarizes work aimed at providing a rapid and accurate alignment technique for troposcatter antennas. An initial program, "Antenna Alignment Study," performed under contract F30602-74-C-0276 established a basis for a new alignment procedure that is based on received spectrum symmetry rather than received power level techniques presently employed. This initial work though was validated using a Hewlett Packard correlator which was not optimized for inclusion into existing troposcatter radio systems.

The work under the present contract was aimed at providing for an alternate implementation that will ultimately provide for a fieldable piece of hardware that will accomplish the goals of rapid and accurate alignment. Besides providing for rapid alignment it is important to realize that the technique provides for accurate alignment on the great circle path while power level based techniques can only provide for short term alignment which is not necessarily the great circle path and thus requires updating.

Before fielding several issues require further work, these are validation of the alignment technique over the full breadth of troposcatter medium variations, reworking of the experimental model to eliminate erroneous results due to aircraft and further optimizing the implementation.

Based on results and the recommendations for future work the improvement to troposcatter alignment is viable and much closer to delivery to the field.

Paul Sierak

PAUL SIERAK
Project Engineer

Section 1

INTRODUCTION AND SUMMARY

Objectives of the Program

Until recently, azimuthal alignment of troposcatter antennas was accomplished by averaging received power to find the proper pointing angle of each antenna. The procedure is arduous, slow, and often inaccurate because of the deep, persistent fading present in the channel. In earlier work, Birkemeier and Sill [1] established a new technique for alignment. According to their method, a monochromatic signal is transmitted and the shape of the received Doppler spectrum is used to determine alignment. The original method involved moving the receiving antennas until the Doppler spectrum was symmetric about zero frequency. When this was accomplished, the receiving antenna was defocused and both antennas moved synchronously clockwise or counter-clockwise until the Doppler spectrum was again symmetric. The beams were then shown to be pointing along the great circle path.

The first Doppler measurements were obtained with a mini-computer that performed an FFT on the incoming data. This method required expensive equipment and operator interpretation of the shape of the spectrum. A less expensive method requiring little operator skill was sought. The next approach made use of the fact that if the spectrum is not symmetric about zero frequency, there will be a non-zero average frequency. The average frequency can be used as a measure of the symmetry of the Doppler spectrum and thus of antenna alignment. There are several known algorithms for the estimation of the average frequency. Birkemeier, Sill, and Fontaine adapted the correlation method [2] so that it could be run in real time on a microprocessor. However, the scheme has a particular disadvantage in that the average Doppler frequency $\bar{\omega}$ will be in error by an amount equal to any frequency difference between the transmitter and receiver clocks. Thus a substantial alignment error would occur with this method if the clocks were not in synchronism as shown by Sill [2].

In this program we provide a microprocessor design together with software to estimate the 3rd central moment or the skew of the Doppler spectrum. The skew provides an alignment indicator that is a direct measure of the symmetry of the spectrum about its mean frequency and therefore does not depend on exact clock synchronization.

In order to use the microprocessor with the TRC-97 radio it was also necessary to provide coherent signal sources for the TRC-97 equipment. This report also details the design of this auxilliary equipment.

Technical Approach to Doppler Moment Computations

In order to compute the skew, we will need to determine various spectral moments of the input process and it is worthwhile to review the significance of these moments.

The first moment, $\bar{\omega}$, is the sum of two independent frequency terms. The first component is due to the frequency difference between the receiver and transmitter clocks, and the second term is due to the lack of symmetry in the spectrum.

The second spectral moment $\overline{(\omega-\bar{\omega})^2}$ is a measure of the spread of the spectrum about the mean frequency.

The third central moment $\overline{(\omega-\bar{\omega})^3}$ is used to estimate the symmetry of the Doppler spectrum about its mean frequency. If the moment is zero, the spectrum is symmetric about the mean; if positive, the spectrum is skewed positively; if negative, the spectrum is skewed negatively.

We begin by defining the skew to be:

$$\text{Skew} = \frac{\int_{-\infty}^{\infty} (\omega-\bar{\omega})^3 \, S(\omega) \, d\omega}{\int_{-\infty}^{\infty} S(\omega) \, d\omega} \qquad (1)$$

where $\bar{\omega}$ is the average frequency defined by [4]

$$\bar{\omega} = \frac{\int_{-\infty}^{\infty} \omega\, S(\omega)\, d\omega}{\int_{-\infty}^{\infty} S(\omega)\, d\omega} \tag{2}$$

Expanding (1) yields

$$\text{Skew} = \frac{\int_{-\infty}^{\infty} \omega^3 S(\omega)\, d\omega - 3\bar{\omega}\int_{-\infty}^{\infty} \omega^2 S(\omega)\, d\omega + 3\bar{\omega}^2 \int_{-\infty}^{\infty} \omega\, S(\omega)\, d\omega \quad \bar{\omega}^3 \int_{-\infty}^{\infty} S(\omega)\, d\omega}{\int_{-\infty}^{\infty} S(\omega)\, d\omega} \tag{3}$$

We now note that the received signal can be written as a narrow band process [5].

$$\begin{aligned} S(t) &= X(t)\cos \omega_c t + Y(t)\sin \omega_c t \\ &= \mathrm{Re}\{[X(t) + jY(t)]e^{j\omega_c t}\} \end{aligned} \tag{4}$$

The quantity X(t) + j(Yt) is known as the complex envelope of the received signal and X(t) and Y(t) are known as it's "inphase" and "quadrature components" respectively. Calling the complex envelope Z(t); we now proceed to determine the Doppler spectrum of the correlation functions of X(t) and Y(t) as follows:

$$Z(t) = X(t) + jY(t) \tag{5}$$

$$\begin{aligned} R_{ZZ}(\tau) &= E\{[X(t) + jY(t)][X(t+\tau) - jY(t+\tau)\} \\ &= R_{XX}(\tau) + R_{YY}(\tau) + jR_{YX}(\tau) - jR_{XY}(\tau) \end{aligned} \tag{6}$$

If we assume that the amplifiers in the quadrature channels have equal gain and phase characteristics, the assumption $R_{XX}(\tau) = R_{YY}(\tau)$ can be made. If we further assume that X(t) and Y(t) are uncorrelated random variables, it can be implied that $R_{XY}(\tau) = -R_{YX}(\tau)$ [5]. Using these assumptions, (6) can be simplified to yield

$$R_{ZZ}(\tau) = 2(R_{XX}(\tau) - jR_{YX}(\tau)) \tag{7}$$

If we define $S(\omega) = F(R_{ZZ}(\tau))$, then (8) follows:

$$\int_{-\infty}^{\infty} S(\omega)\, e^{j\omega 0}\, d\omega = 2\pi R_{ZZ}(0) = 4\pi R_{XX}(0) \tag{8}$$

Papoulis [5] has shown that

$$R_{X\dot{Y}}(\tau) = -R'_{XY}(\tau) \tag{9}$$

This result will be used to calculate $\bar{\omega}$. The differentiation relationship of the Fourier transform allows us to write [7]:

$$\frac{1}{2\pi} \int_{-\infty}^{\infty} j\omega S(\omega) e^{j\omega}\, d\omega = R'_{ZZ}(\tau) \tag{10}$$

Using this relationship, it follows that

$$\int_{-\infty}^{\infty} j\omega S(\omega) e^{j\omega 0}\, d\omega = 2\pi R'_{ZZ}(0) \tag{11}$$

$$\int_{-\infty}^{\infty} \omega S(\omega)\, d\omega = \frac{2\pi}{j} R'_{ZZ}(0)$$

We combine (9), (10), and (11) and use the fact that $R_{XX}(\tau)$ is even to find $\bar{\omega}$. Thus

$$\bar{\omega} = 4\pi R_{XX}(0) \tag{12}$$

Using (10) twice, we get the second moment

$$\int_{-\infty}^{\infty} \omega^2\, S(\omega) e^{j\omega 0}\, d\omega = -2\pi R_{ZZ}(0) \tag{13}$$

Papoulis [5] has also shown that

$$R_{ZZ}(\tau) = R''_{ZZ}(\tau) \tag{14}$$

Since $R_{XY}(\tau)$ is an odd function, even derivatives at $\tau=0$ are zero. This allows us to combine (13) and (14) to yield:

$$\bar{\omega}^2 = 4\pi R_{XX}(0) \tag{15}$$

Finally, the third moment is computed in the same fashion.

$$\int_{-\infty}^{\infty} \omega^3 S(\omega) e^{j\omega 0} d\omega = \frac{-2\pi}{j} R'''_{ZZ}(0) \tag{16}$$

$$R'''_{ZZ}(0) = R_{\dot{Z}\ddot{Z}}(0) \tag{17}$$

$$\bar{\omega}^3 = 4\pi R_{XY}(0) \tag{18}$$

We now combine (8), (12), (15), (18), and (3) to yield the formula for the skew:

$$\text{Skew} = \frac{R_{\dot{X}\ddot{Y}}(0)}{R_{XX}(0)} - \frac{3R_{X\dot{Y}}(0)R_{\dot{X}\dot{X}}(0)}{R_{XX}(0)R_{XX}(0)} + \frac{2[R_{X\dot{Y}}(0)]^3}{[R_{XX}(0)]^3} \tag{19}$$

This is the theoretical formula for the relative skew. Several assumptions about the process have been made. They are $R_{XX}(\tau) = R_{YY}(\tau)$, $R_{XY}(\tau) = -R_{YX}(\tau)$ and that the X(t) and Y(t) processes are jointly stationary. For the computation algorithm to function properly, all of these assumptions must hold.

Practical Implementation of the Skew Estimator

The validity of each of the assumptions made earlier must be examined in light of the data. The most basic assumption made earlier is that the in-phase and quadrature components of the signal are uncorrelated random variables, that is $R_{XY}(0) = 0$. It is clear that if both channels possess a DC term, this assumption cannot hold. All amplifiers, no matter how carefully designed, will have some DC offset. This is especially true of amplifiers that must operate at frequencies close to zero. The software must preprocess the data to remove the offset.

The second major assumption is that $R_{XX}(0) = R_{YY}(0)$. This statement implies that the statistics of the channels are equal and that the gains of the amplifiers in both channels are equal. If this is true, we should be able to interchange the roles of X(t) and Y(t) and get the same results. This does happen with data that is not properly preprocessed. Certain terms are immune to differences in the X and Y channel gains. In practice, terms that contain both X and Y are immune to interchanging roles. Terms such as $R_{XX}(\tau)$ or $R_{YY}(\tau)$ do not have mixed terms and will be vulnerable to both short term and long term variations in the gain. These terms are particularly sensitive because they contain derivatives which accent the temporal variations in channel gain.

The long term variation in the difference in the amplifier gains can be taken care of in software by correcting the gain of the Y channel by the ratio of the rms value of X(t) and Y(t). This is slow agc which cannot compensate for the short term variations in $R_{XX}(0)$ and $R_{YY}(0)$. To correct for these short term variations we have obtained good results by taking the geometric mean of $R_{XX}(0)$ and $R_{YY}(0)$ and using this number to replace $R_{XX}(0)$ in the 2nd term in (19).

The following section describes the microprocessor implementation of these programming objectives.

Summary of Results

Tests of the Slope algorithm on the RADC link indicated that alignment could be accomplished to within about 0.3° or about 1/10 of a beam width with a period of about ten minutes. The Slope Algorithm actually measures $\bar{\omega}$, the average Doppler shift and its success depends on exactly synchronized clocks.

The skew algorithm indicated that the antennas could be aligned to 1/3 degree or better, also in a time period of about ten minutes. These measurements were based on single observations of displayed skew which occur once each second. Visual averaging would lead to substantial improvement in expected accuracy, but such improvement is not quantified in this report. Exact clock synchronization was not required in alignment using skew indication. Instead, $\bar{\omega}$ was set equal to zero by varying the receiver clock before each skew measurement was made.

Organization of Report

The microprocessor hardware and software design is summarized in Section 2. Section 3 details the design of the frequency synthesizers and detector components necessary to interface the microprocessor to the TRC-97 and the TRC-170 equipment. The antenna alignment tests on the RADC link are presented in section 4. Appendix A contains the microprocessor drawings. Appendix B lists processor program. Appendix C presents complete drawings concerned with the design and fabrication of the synthesizer modules together with parts lists. Appendix D contains a more detailed theoretical description of the nature of troposcatter Doppler spectrum and the estimation of its parameters.

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Section 2

MICROPROCESSOR HARDWARE AND SOFTWARE

Introduction

A block diagram of the microprocessor hardware is shown in Fig. 2.1. The major components consist of the 8085 microprocessor, 4-2716 PROMS (one with test data, one with a debugging monitor and two with the alignment programs), AM9511 arithmetic processor, AD571 10-bit A/D converter, 8251 serial terminal andphone line interfaces for the program development and front panel switch, light and BCD display hardware. The schematics for the microprocessor system are in Appendix A. The system operates in five modes (reset, clock, slope, correlation, and skew) that are front panel push-button selectable by the operator.

The reset mode resets all hardware in the system and then uses the slope algorithm to process five seconds of digitized test data that is stored in a PROM. This provides a self test for the system. The clock mode is used to measure and display the offset frequency between the transmitter and receiver oscillators while the slope, correlation and skew modes are the three alignment algorithms. Front panel switches are scanned at a ten per second rate by the program and whenever a switch is found pressed the program is restarted using the algorithm that is indicated by the switch.

A five digit BCD display provides the operator with a floating point (four-digit mantissa, one-digit exponent) digital readout of alignment information. In all cases the displayed quantity represents an average that has been exponentially averaged with a time constant of several seconds. Although the time constant is several seconds the display is updated once a second with the new value of the running average.

The arithmetic processor allows arithmetic expressions to be programmed very easily -- much like a hand calculator. The 10-bit digitized values for the in phase and quadrature signals are immediately converted

Figure 2.1

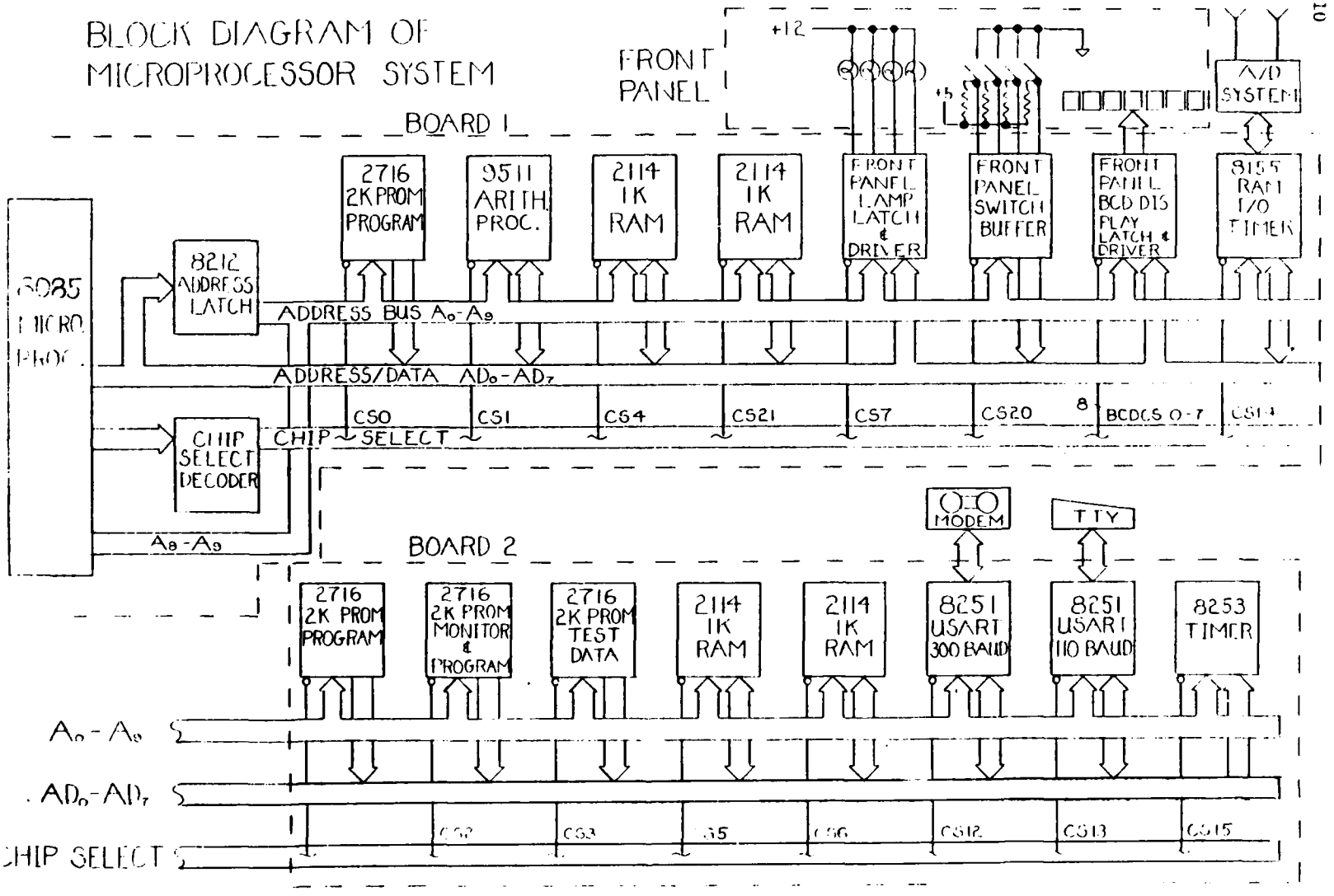


Figure 2.1

to a 32-bit floating point format by the arithmetic processor and all subsequent processing of these is done using the floating point format.

Two programs are listed in Appendix B. One in FORTRAN and one in 8085 assembly, are included. The FORTRAN program was used on a Raytheom 704 with tape recorded data to develop the processing algorithms. A deliberate attempt was made to maintain a close correspondence between the FORTRAN and the 8085 code and in most cases each line of the FORTRAN program is included as a comment in the 8085 instructions that are used to implement the FORTRAN expression.

General Signal Considerations

The inphase and quadrature signals are filtered with analog filters before they are digitized by the A/D system on the microprocessor board. The pass band of these filters is 0 to 30 Hz when the clock and skew algorithms are used and 0.3 to 20 Hz when the slope and correlation algorithms are used. In this section and in the program listings the inphase and quadrature signals will be called X and Y respectively.

The tape recorded data used in the FORTRAN program was sampled at a 100 sample per second rate. The programs were written with the intent of using a timer-drive microprocessor interrupt to sample X and Y every 0.01 seconds, accumulate data from 100 samples, and update the display once a second with the new data included in the running average. The timer interrupt was not implemented because the microprocessor program when operating at full speed result in approximately a 100 sample per second sampling rate.

The displayed variables for clock or antenna alignment algorithms are averaged quantities and hence statistical in nature. Two conditions exist that can introduce large errors in these averages. One situation is when X and Y simultaneously become very small and the other is reflections from

aircraft. The first situation is easily programmed: the incoming data are ignored whenever the magnitude of both X and Y are less than 2% of the maximum value.

The aircraft contamination is more difficult to detect. Aircraft introduce higher than normal frequencies into X and Y and these are particularly troublesome in the skew algorithm that requires the second derivatives of X and Y. In an attempt to eliminate data with aircraft contamination the frequency X and Y is estimated from each successive pair of samples and the data ignored whenever the frequency exceeds 8 Hz. The first and second derivatives are calculated using

$$\Delta X_N = \frac{X_{N+1} - X_{N-1}}{2} \qquad \Delta^2 X_N = X_{N+1} - 2X_N + X_{N-1}$$

Thus whenever data are ignored, three valid samples are required before the derivative calculations can continue.

Measurements made on the inphase and quadrature detector outputs indicated that both contained non-zero dc components and that the gain of the two detectors varied slightly. Both effects are removed in the processing by computing long time dc and mean square values of the detector outputs and equalizing the sampled values with them:

$$X_i = X_i - X_{dc} \qquad Y_i = (Y_i - Y_{dc})\sqrt{\frac{\overline{X^2}}{\overline{Y^2}}}$$

As mentioned earlier an exponential averaging technique is used to form a running average of X_{dc}, $\overline{X^2}$, $\dot{X}Y$, skew, etc. If A_{N-1} is the current value of the running average and I_N is the new input to be added to the average the new average is computed from

$$A_N = A_{N-1} + \frac{I_N - A_{N-1}}{N}$$

8085 Processing - Overall View

The four FORTRAN subroutines described above perform identical processing in the 8085 microprocessor system. A brief description of additional routines is given in this section. The X, Y sample pair is obtained by the subroutine ATOD. The routine will return either test data that is stored in PROM or will sample live data with the A/D system. Test data is returned if the AC power system has just been turned on or if the operator has pushed the RESET button; otherwise, sampled live data is returned.

The front panel switches are scanned with the routine RDFRNT. If a switch is found depressed the system is reset and a logical flag corresponding to the switch is set. Other subroutines use the flags to determine the processing that is required.

A scheduler routine, SCHED, is used to direct the real-time processing. Every call to SCHED results in a call to ATOD for a new data sample and a call to PROCES to process the data sample. Every 10th call to SCHED results in a call to RDFRNT to scan the front panel switches and every 100th call produces a call to UPDATE and DISPLY. As mentioned earlier the system was designed for a programmable timer to produce a call to SCHED every .01 sec but this is not implemented. Instead each return from SCHED is immediately followed by another call to this routine.

Program Implementation of Clock and Alignment Algorithms

Under ideal conditions of noise free, zero doppler shift, transmission with the transmitter and receiver oscillators operating at a frequency difference of ω_d, the X and Y signals become:

$$x(t) = \cos \omega_d t \quad \text{and} \quad y(t) = \sin \omega_d t \ .$$

where N is the number of samples that have been taken. This algorithm acts like an RC averaging circuit with a time constant of NT seconds where T is the time between new inputs I_N. Thus new information is weighted heavily and old information is forgotten. In addition N is varied during the measurement starting at a value of one and increasing to a maximum of 16 or 60 depending on the variable that is averaged.

FORTRAN Processing - Overall View

The FORTRAN program has four subroutines INITAL, PROCES, UPDATE, and DISPLY for processing the data and each of these has a counterpart in the 8085 program. A program listing of the FORTRAN program is in Appendix A. The data used in the FORTRAN is read in from magnetic tape in blocks of 1024 digitized (12-bit), pairs of samples X_i, Y_i by the main program. The main program then passes one pair of samples at a time to the subroutine PROCES just as the A/D subroutine in the 8085 system would pass one pair to the 8085 PROCES routine. Each subroutine contains the processing necessary for all four algorithms: clock, slope, correlation, and skew but uses logical flags to select only the processing that is necessary for the algorithms in use when the subroutine is called.

The subroutine INITAL is used to initialize all arrays, exponential averaging parameters, etc. each time a run is started or whenever the operator decides to reset or clear the program of accumulated data.

The PROCES routine is called once for each X, Y pair of samples. Data are tested for validity, derivatives calculated, one-second sums of dc and mean square values of X and Y are tabulated for the 100 samples that are passed to PROCES. After 100 samples (equivalent to 1 second of data) are processed, the accumulated runs are used by UPDATE to add to the running averages of these variables and the parameters in PROCES are reset to allow for the accumulation of the next 100 samples. After the running averages are updated the routine DISPLY is called to display the new values.

The frequency ω_d can be obtained by defining $\theta = \tan^{-1}(y/x)$ and calculating

$$\frac{d\theta}{dt} = x\frac{dy}{dt} - y\frac{dx}{dt} = \omega_d .$$

In terms of signals that are sampled every Δt sec the difference frequency is estimated as

$$f_d \approx \frac{\Delta\theta_i}{2\pi\Delta t} = \frac{X_i\Delta Y_i - Y_i\Delta X_i}{2\pi\Delta t}$$

The running average (16 sec time constant) of the quantity $\frac{\Delta\theta_i}{2\pi\Delta t}$ is continuously displayed when the clock algorithm is used.

The slope algorithm displays a running average of the quantity $\frac{(\Delta X_i)Y_i}{\overline{x^2}\Delta t}$. The X_i and Y_i used in this expression and in all calculations are the sample values with the dc removed and normalized to the same mean square value. The $\overline{x^2}$ term is a running average of the mean square value of x that is used to normalize the slope statistic so that it is independent of signal strength.

The cross correlation between continuous function of time x(t) and y(t) is defined as $R_{xy}(\tau) = \overline{x(t)y(t-\tau)}$. For sampled signals the cross correlation becomes

$$R_{xy}(m\Delta\tau) = \overline{x(k\Delta t)y(k\Delta t - m\Delta\tau)}.$$

The cross correlation is computed for $-1.5 < \tau < 1.5$ seconds by using $\Delta t = \Delta\tau = 0.03$ sec and a table to store the 100 values for $R_{xy}(m\Delta\tau)$ that correspond to $-50 < m < 50$. Since .03 is three times the sampling interval, every third sample of raw data is used in calculating the cross correlation. These data samples are placed in a "delay line", first in first out type table, 50 samples long for X and 100 samples long for Y. As each X sample reaches the bottom of the table it is correlated with the 50 samples of Y forward and backward in time and then discarded. Since the alignment criteria

with the correlation algorithm is to minimize the absolute slope about $\tau=0$, the slope of a line from the origin to the maximum value of $R_{xy}(m\Delta\tau)$ is the quantity that is displayed to the operator.

The equation for skew was developed earlier; and although it is a straightforward arithmetic calculation, it is a sensitive measure with a larger variance than the slope or correlation measures. This is due to the subtraction of terms in the expression that frequently are very large and nearly equal.

Summary and Recommendations

The hardware and software have proven to be very trouble free and reliable. The higher doppler frequencies that were present in data on the RADC link, but not on the UW link, frequently caused the system to reject the data as aircraft contamination. Other means of detecting aircraft reflections should be tried and the most promising of these is to look for rapid fluctuations in envelope that exceed a peak to peak threshold.

Section 3

INTERFACING WITH TRC-97 AND TRC-170

Frequency Synthesizer Design

The Air Force troposcatter TRC-97 and TRC-170 equipment requires a frequency synthesizer that will convert a precision frequency reference into coherent 70 MHz and 50 MHz outputs. The receiver also requires a quadrature detector for its 70 MHz intermediate frequency signal. A block diagram of the system is shown in Appendix C, Figures C1 and C2. As the figures show the radios are to use their own internal 50 MHz and 70 MHz sources when operated in the non-alighment mode and the synthesizer's coherent oscillator signals in the alignment mode. Coaxial relays are included in the aligner for switching these signals. The 50 MHz and 70 MHz synthesizer outputs must have a frequency stability of at least 1 part in 10^{10}, and both the 50 MHz and the 70 MHz outputs must provide 18 dbm to a 50 ohm resistive load. Harmonic content within 10 MHz of the fundamental was to be down at least 20 db.

These specifications were met with an "indirect" frequency synthesizer, employing phase locked loops (PLL) for frequency multiplication. The basic designs for these synthesizers are shown in Figure C3 and C4.

The Precision Quartz Clock

The precision 5 MHz crystal oscillator which provides the source for the phase lock loops is a double-oven Vectron model CO-246V-1 oscillator with frequency stability of 1 part in 10^{10}. The oscillator frequency can be externally controlled by a DC voltage. The connection diagram for the frequency standard is shown in Figure C5.

The 25 MHz and 35 MHz Phase Lock Loops

The 5 MHz reference signal is power divided between the 50 MHz and 70 MHz phase locked loops. The basic phase locked loop design is shown in Figure C6. The voltage controlled oscillators, VCO's, oscillate at half

the desired output frequency (35 MHz for the 70 MHz unit and 25 MHz for the 50 MHz unit) because integrated circuit PLL's are limited to a maximum frequency of about 35 MHz. A balanced mixer is used to double the VCO frequencies to the desired 70 MHz or 50 MHz values.

The XR215 PLL integrated circuit chosen consists of a phase detector and VCO. The lowpass filter corner frequency for the control signal and the VCO frequency range are determined by an external capacitance connected to the XR215 chip. The frequency divider is the 93S05 variable modulo counter. For the 70 MHz circuit it is wired to frequency divide by 7; for the 50 MHz circuit it is wired to divide by 5.

The 70 MHz phase locked loop schematic is shown in figure C7. Due to the variation in characteristics from one VCO to another the VCO capacitor C107 must be selected to give the correct VCO frequency range. C107 should be no larger than 12 pF. C105 and C106 determine the corner frequency of the tuning voltage low pass filter. The filter transfer function has a single pole at $1.33 \times 10^6 \frac{\text{rad}}{\text{sec}}$ or 212 KHz. R100, the VCO free run frequency adjusting resistor, should be adjusted to allow the PLL to achieve lock. Q100 is part of a of a common emitter amplifier that raises the VCO signal amplitude to the level required to drive the Schmidt Trigger, U101. The Schmidt Trigger converts the analog 35 MHz signal to a TTL compatible signal to prevent erratic operation of the frequency divider which follows it. The frequency divider, U102, takes the 35 MHz signal from the Schmidt trigger and divides its frequency by 7. Thus the output of U102 has a frequency of 5 MHz. This signal is coupled to the phase detector in U100 where it is phase compared with the 5 MHz frequency standard. The output of the Schmidt trigger is also coupled to [101 which is part of an emitter follower power amplifier. This power amplifier drives a double balanced mixer, U103, with the 35 MHz signal. The mixer is used as a frequency doubler to generate the desired 70 MHz signal. This signal is passed to the 70 MHz amplifier for amplification and band pass filtering.

The 50 MHz phase locked loop schematic diagram is shown in Figure C8. and its parts list follows. The 50 MHz PLL is similar to the 70 MHz PLL. The only differences are a larger coupling capacitance, C214, a different wiring of the frequency divider to divide by 5 instead of 7 and a resistor, R218, in series with the 50 MHz output. This resistor attenuates the 50 MHz output to prevent it from saturating the 50 MHz amplifier and generating excessive harmonic levels.

The 70 MHz Amplifier

The original design with minor modifications was used for the 70 MHz amplifier. The schematic diagram is shown in Figure C9. The output of the amplifier goes to the detector in the receiver and to jack J1 on the transmitter A-17 assembly by way of the 70 MHz coax relay.

The original design with minor modification was also used for the 50 MHz amplifier. The schematic diagram is shown in Figure C10. R400 was added to the amplifier input to eliminate self oscillation. L400 and C400 were also added to the amplifier input as a series tuned circuit to reduce the 75 MHz spurious output from the 50 MHz phase locked loop.

The Quadrature Detector and Low-Pass Filter

The receiver also requires a synchronous quadrature detector. This detector must demodulate the 70 MHz intermediate frequency signal into its quadrature components. These signals must then be low pass filtered with a corner frequency of 20 Hz. The schematic diagram of the detector is shown in Figure C11. The low pass filter contained in the detector was designed to have a voltage gain of 10. This should result in 2 volt peak-to-peak output levels from the X and Y channels under nominal channel conditions. This is the level required to drive the following stage which is a DC blocking filter. The low pass filter is a Sallen and Key configuration designed to have the following transfer function:

$$H(s) = \frac{10}{s^2 + 178(\frac{rad}{sec})s + (1.58 \quad 10^4)(\frac{rad}{sec})^2}$$

This results in a two pole low pass filter with a corner frequency of 20 Hz and a Q of 0.707. This Q gives the steepest possible skirt without any passband ripple.

Low-Pass, Band-Pass Filter

The output of the detector module is next fed to the Low-Pass, Band-Pass Filter. One section of this filter additionally attenuates frequencies above 20 Hz by 6 db/octave and outputs this low-pass signal to the microprocessor to be used in the "slope" program to compute the average Doppler frequency or the slope of the cross-correlation function at zero lag. The band-pass filter section adds a high pass filter in cascade to the low-pass section to remove frequency components below 0.3 Hz. The band-pass filtered outputs are fed separately to the microprocessor to be used to compute the average frequency whenever a strong specular signal at zero Doppler shift exists in the signal. In tests at RADC this output was not used. The schematic diagrams and parts layout are found in Fig. C11 and Fig. C23, respectively.

The Power Supply

The frequency synthesizer power requirements are 5 volts for the phase locked loops, 12 volts for the phase locked loops, amplifiers and detector, 24 volts for the frequency standard and -12 volts for the detector. The power supply schematic diagram is shown in Figure C12. The power supply module contains the bridge rectifiers, filter capacitors and 24 volt regulator. The outputs of the module are 24 volts regulated for the frequency standard and relay coils, 40 volts unregulated for the 12 volt and 5 volt regulators and -20 volts unregulated for the -12 volt regulator. The 12 volt, 5 volt, and -12 volt regulators are preceeded by voltage dropping resistors to reduce the voltage regulator dissipation. The 12 volt, 5 volt, and -12 volt

regulators are mounted on the frequency synthesizer base plate for heat sinking. Because the transmitter does not have a detector circuit, components C601, R602, CR601 and U603 are not used in the transmitter power supply.

Each phase locked loop, amplifier and detector circuit was built on its own printed circuit board and mounted in its own box. All power supply connections to the boxes are made with feed through capacitors. All other connections to or between boxes are made with TNC connectors or feedthrough terminals. This connection scheme is used to eliminate electro-magnetic interference between the frequency synthesizer and other system components.

Test Results

When the synthesizers were tested, the phase locked loop selected capacitors and VCO tuning potentiometers were adjusted while observing the 50 MHz and 70 MHz signal outputs with a spectrum analyzer. These components were adjusted to values that allowed the phase locked loops to achieve lock at 50 MHz and 70 MHz after the internal temperatures stabilized with an ambient temperature of 25° C. The 50 MHz and 70 MHz output spectral purities and signal levels are recorded in photographs C13 and C14. The units were each driving a 50 ohm resistive load for these results. It can be seen from the photographs that the signal output level requirements are met with these synthesizers.

Additional Suggestions

The spectral purity of the frequency synthesizers could be improved at an added cost. The noise sidebands on the 50 MHz and 70 MHz signals could be improved by replacing the RC VCO's in the phase locked loops with voltage controlled crystal oscillators, VCXO's. VCXO frequencies would be more stable with age and temperature variations. The use of VCXO's should also reduce the VCO frequency variations from IC to IC. This would eliminate the need for selected capacitors in the PLL circuits. The XR215 can be used as a VCXO.

The spectral components that are spaced every 5 MHz about the 50 MHz and 70 MHz desired signals could be greatly attenuated by installing crystal filters between the phase locked loops and amplifiers. An additional stage would need to be added to compensate the insertion loss.

Printed Circuit Boards

Art work for PC boards used in the synthesizers are shown in Appendix C Figures C15-C18.

Parts Layout

Layout of parts for the various synthesizer modules are shown in Figures C19-C22. The 50 MHz PLL is identical to the 70 MHz parts layout shown, except its parts are numbered in the two-hundreds.

Parts Lists for Synthesizer and Filter Modules

See pages C.28 through C.36, Appendix C.

TRC-170 Interfacing Requirement

The TRC-170 equipment is fully coherent using automatically controlled clocks to drive its frequency synthesizers. As such there is no problem in interfacing this radio with the aligner's microprocessor. The aligner's detector package, however, must be driven by the TRC 170's detector, which in turn must be driven by a 70 MHz source. This source is provided by the aligner's synthesizer using its own internal 5 MHz standard or by substituting the TRC-170's 5 MHz standard. The latter would be preferred, since it eliminates the need to set the clock according to skew estimation procedure outlined in Section 4.8.

Section 4

TEST RESULTS

UW Link Tests

The antenna aligner tests were performed in accordance with the Proposed Test Plan/Procedures (clin item 0004). Test efforts on the 940 MHz University of Wisconsin link held on 12/14/79 and 12/15/79 were largely unsuccessful as a result of more-or-less continuous aircraft intrusions on both days. Moreover, it proved impossible to skew the Dopple spectrum by azimuthally displacing the receiving antenna. This is possibly explained by the occurrence of equal and opposite cross-path wind fields in scattering layers of equal cross-section, although we have no meteorological proof of such a situation existing.

UW Test of Skew Algorithm

We observed the skew algorithm to correctly reflect the changing slope of the Doppler spectrum when an aircraft crossed the common volume, but unfortunately, the skew measure also was influenced by the clock setting contrary to theoretical expectations. We speculated that this was the result of a program deficiency that causes the 1st and 2nd derivatives of the quadrature components of the received data to be underestimated when the fading is too slow. Fading on these days was extremely slow due to a strong specular component in the received signal. We expect faster fading at 4 GHz to mitigate this problem.

UW Test of Slope Algorithm

Aircraft traversals provided the only way to test the slope algorithm. The slope changed sign as the aircraft crossed the great-circle in every case qualitatively indicating proper operation.

UW Test of Clock Setting Algorithm

This algorithm was tested by varying the 5 MHz clock frequency in the receiver. The average frequency displayed agreed with the amount of observed clock offset.

UW Test of Correlation Algorithm

The correlation algorithm is protected from false data during on aircraft intrusion by a scheme that rejects an entire 30 second data stream if the phase of the received signal changes by more than eight degrees from one sample to the next (0.1 sec). Since aircraft were particularly numerous, this algorithm succeeded only on brief occasions and could not be evaluated realistically. Later it turned out that fast fading on the RACD link was able to activate the protective device and therefore defeat the estimation algorithm.

Conclusions from UW Tests

While these tests were far from satisfactory they indicated that we could expect proper operation under the conditions to be expected on the shorter, higher frequency RADC link. We therefore begin tests in Verona, New York on 1/17/79.

RADC Link Tests

The RADC TRC-97 link from Ontario, New York to Verona, New York was operated at 4880 MHz using Cesiuum-beam clocks and HP synthesizers to establish all signal sources in the transmitter and receivers. Detection was accomplished using the coherent quadrature detector package of the Antenna Aligner together with the 70 MHz reference signals established by the 5 MHz Vectron oscillator also contained in the aligner. Observation

of the X-Y display of the quadrature components on an oscilloscope revealed random phase jitter of approximately ± 45° on the received signal. This was pure phase jitter that apparently was generated in the TRC-97 transmitter. (No phase jitter was observed when the receiver was fed the 4880 output from a coherent source). This phase noise caused us no problem because most of its frequency components were above 20 Hz and were therefore eliminated by the low-pass filters in the aligner. Nevertheless, such jitter constitutes a potential source for error if the filter bandwidths are expanded as explained later. Other troubles in getting the link up were due to cold environmental temperatures (< 40° F) at the Verona site. In particular the aligner's phase-lock loops were reluctant to lock and the microprocessor clock chip refused to operate until raised to room temperature.

Test of Slope Algorithm, Step 1

The slope algorithm measures the presence or absence of a cross-correlation function by measuring its slope at the origin. Zero slope implies that the Doppler spectrum is symmetrical about zero frequency shift. In order to provide unambiguous results, the shift due to clock error must be zero. In these tests the signal contained no zero-Doppler-shifted component so the receiver clock could not be set to zero beat. We therefore set the aligner's clock to zero beat with the Cesium-beam standard supplying the receiver. The slope display was sampled and recorded each second for 60 seconds. Three such runs were made -- the first two about one hour apart, and the third on the next day. The data summary is presented in Table 1 below. In each case the transmitting antenna was set on the great-circle and both antennas were focused. The slope, S, in volts^2/sec is given for the receiving antenna displaced ± 1° from the great-circle.

Table 1. Slope Estimation for Step 1 of Alignment Process							
	Rec. Ant. = 1° N of great-circle				Rec. Amt. = 1° S of Great Circle		
Run 1	3:00 EST 12/21/79	$\bar{S}$=-1.68	σ_S=.27	$\bar{S}/\sigma_S$=6.2	$\bar{S}$=1.09	σ_S=.14	$\bar{S}/\sigma_S$=7.8
Run 2	4:30 EST 2/21/79	$\bar{S}$=-1.08	σ_S=.33	$\bar{S}/\sigma_S$=3.20	$\bar{S}$=2.56	σ_S=.22	$\bar{S}/\sigma_S$=11.6
Run 3	8:30 AM 12/22/79	$\bar{S}$=-1.008	σ_S=.33	$\bar{S}/\sigma_S$=3.05	$\bar{S}$=1.46	σ_S=.39	$\bar{S}/\sigma_S$=3.75

From the table above we estimate the alignment accuracy for the first step in the procedure by noting that the ratio of the mean slope $\bar{S}$ to the standard deviation of the data, σ_S, has a minimum value of 3.05 in Run 3. This means that 1 degree of receiving antenna offset resulted in a mean slope reading about three times larger than the rms fluctuations in the displayed slope data. The expected accuracy is thus about 1/3 of a degree. That is, treating the 1 second samples as independent data, a single sample of the slope measure has probability of .64 of lying within $\pm$ one standard deviation of the true mean. Note that in Run 1 on the previous day about twice this accuracy would have been obtained. Note, however, that the increase appears to be due to increased $\bar{S}$ when the receive antenna was 1° North and due to decreased rms fluctuations when the antenna was 1° South. Presumably spatial and temporal nonstationarities in the scattering structure were responsible for these variations. The minimum obtained accuracy of 1/3° is less than the back-lash in the TRC-97 antenna gearing and is therefore probably sufficient in this case. The actual obtainable accuracy is much better, since the operator of the aligner mentally averages as he observes the displayed numbers. The rms value of the fluctuations drop with $1/\sqrt{N}$ where N is the number of independent observations averaged. While the one-second data values displayed are not entirely independent, a substantial improvement is certain to be obtained in actual practice by a experienced operator.

Test of Slope Algorithm, Step 2

Step one of the alignment procedure accomplishes straddling antenna beams. In step two of the procedure the receiving antenna is defocused and the beams are synchronously swung until the cross-correlation slope is again averaging zero. The beams are then in great-circle alignment. Several runs were made using about 60 samples of slope data with the beams displaced by various equal and opposite incremental angles starting at a maximum of $\pm$ 1 1/2°. The results are tabulated in Table 2 below. All five runs were made within one hour from 12:10 EST to 13:10 EST on 12/21/79.

Table 2. Slope Estimation for Step 2 of Alignment Procedure

Run	Antenna Setting from Calibration on Mast.		$\bar{S}$	σ_S	$\bar{S}/\sigma_S$	Remarks
1	R = 1 1/2° N Focused	T = 1 1/2° S Focused	-.04	.308	---	Both antennas focused
2	R = 1 1/2° N Defocused	T = 1 1/2° S Focused	+1.19	.22	5.4	Receiving antenna defocused
3	R = 1° N Defocused	T = 1° S Focused	+.98	.20	4.9	
4	R = 1/2° N Defocused	T = 1/2° S Focused	+.11	.24	---	Both antennas very close to great circle
5	R = 0° Defocused	T = 0° Focused	-.783	.32	---	

Note from Run 4 in Table 2 that the data implies the correct antenna settings would be about 1/3° N for receiving antenna and 1/3° S for the transmitting antenna. This is just the amount of the apparent back-lash in the antenna pointing gear train and accounts for the displacement due to the wind loading on each antenna. (A north to south wind prevailed during the experiment.)

Test of Skew Algorithm, Step 1

It was noted in preliminary checks of the skew estimation algorithm that the measure was sensitive to the receiver clock setting which is contrary to theoretical expectations. It was possible to align the antennas with an improper initial clock setting using the skew algorithm, however. To accomplish this we simply set the clock to force the average "Doppler" frequency $\bar{\omega}$ equal to zero as indicated by the clock mode display of the aligner. With $\bar{\omega}$ equal to zero the skew mode of the aligner then displays the true skew measure of the received spectru. To estimate the alignment accuracy we measured skew with the receive antenna set off the great circle. Data for two antenna positions are shown in Table 3. The transmit antenna was set to the zero degree mark or a true position of about 1/3° N. (The wind now was south or north across the link). The receive antenna was set at 1° S or a true position of about 2/3° S for Run 1. For Run 2 the receive antenna was set at 1° N or a true position of about 1 1/3° N. The skew measures correctly reflect these antenna positions as shown in Table 3 below.

Table 3. Skew Estimation for Step 1 of Alignment Procedure

Run	Antenna Setting Both Antennas Focused		$\bar{SK}$	σ_{SK}	$\bar{SK}/\sigma_{SK}$
1	R = 2/3° S true	T = 1/3° N true	-176	3.95	4.4
2	R = 1 1/3° N true	T = 1/3° N true	+428	114	3.75

In order to estimate the alignment accuracy from this data note from Run 1 that a displacement of the receiving antennas of only 1/3° from its correct straddle point produced a significant average skew value $\bar{SK}$ that was 4.4 times larger than its standard deviation. This implies an alignment accuracy of about

1/12 degree. In Run 2 the receive antenna was displaced twice as far as in Run 1 and also toward the displaced transmit antenna. As a result the Doppler spectrum is strongly skewed in the opposite direction to that of Run 1. Note $\overline{SK}$ has correspondingly changed sign and increased in magnitude over Run 1. The standard deviation of the skew has also increased so that the ratio of average skew to its standard deviation remains close to 4. More data would be required to determine whether or not this ratio tends to remain constant with displacement of the composite antenna pattern. Nevertheless, these data suggest that the Skew estimator is as good or better than the Slope estimator as an alignment indicator, but with the advantage that absolute clock setting accuracy is not a requirement with Skew. The Skew approach does depend on the extra step of setting the clock to make $\bar{\omega}$ equal to zero before each Skew measure is attempted. This step is not time consuming and we estimate from this experience that complete Step 1 and Step 2 alignment procedures could be completed in about ten minutes with the TRC-97 as configured in these experiments. Because of time limitations it was not possible to attempt Step 2 of the alignment procedure. There is no reason to believe that the results would differ greatly from those experienced with the slope algorithm since ratios of mean to standard deviation of about 4 were observed with both Slope and Skew measurements.

Overview of Test Results

Both the "slope" and "skew" estimation techniques were shown to provide a sensitive measure of antenna misalignment and a fast and accurate method of alignment based on these estimates was demonstrated. The "correlation" technique could not be tested because the program was devised to eliminate fast fading data as a safeguard against aircraft signals. The fading rate on the RADC link was so fast that the scheme was nearly always defeated. However, both "slope" and "skew" were sufficiently successful to perhaps negate the need to test the correlation approach.

Accuracy and Alignment Time

Both the successful modes of operation provided azimuth alignment to within ± 1/3 degree of the great circle, which is about the same as the backlash on the TRC-97 antenna gear drive. This degree of accuracy is implied by the fact that at 1/3 degree error, the average value of the displayed quantity equaled the rms value of its 1-sec fluctuation. The displayed quantity is derived from 16 seconds of data, and this is the amount of time required for the rms fluctuation to reach their minimum value after data taking is started. It is important to point out once again, that an operator of the aligner would tend to mentally average the 1-second displayed numbers before making an estimate of the misalignment. If 15 seconds of observations are permitted, a total of 30 seconds would elapse before each adjustment of the beam could be made. Assuming about ten such adjustments are necessary to reach final alignment, 300 seconds of data processing time would be required to align one antenna using the slope technique. Data averaging by the operator will also tend to improve the alignment accuracy, so it would be reasonable to predict that accuracy at least twice as good as ± 1/3° could be achieved in practice.

Comparison of Slope and Skew Methods

The tests indicated that the slope and the skew methods achieved essentially the same degree of accuracy. However, the slope method is not usable unless some method is available to synchronize the transmitter and receiver clocks. If the propagation medium provides a strong specularly reflected signal with zero Doppler shift the aligner's clocks can be synchronized by zeroing the average frequency read on the display using the aligner's "clock" mode. In the absense of a specular signal it is necessary to use the skew mode and to correct the receiver clock at each new antenna position. Correcting the clock takes an additional 10 or 15 seconds at each antenna position which about doubles the time required to align

the antennas. An estimate of the total time to align using the skew mode is thus about 600 seconds.

Our experience at troposcatter frequencies near 1 GHz indicates specular layers are usually present. At the TRC-97 frequency near 5 GHz specular reflections are much less likely to occur. Based on this the skew algorithm is the only choice for the TRC-97 radios providing alignment is about 10 minutes for each antenna. Newer coherent radios such as the TRC-170 with atomic frequency control would be able to use the slope algorithm and achieve alignment in about 5 minutes for each antenna.

Connecting the Aligner to the TRC-97

The overall block diagrams in Fig. C.1 shows the aligner attached to the TRC-97 transmitter and receiver when the system is in the alignment mode. This mode is accomplished by placing the align-nonalign front panel switch in the align position which applies the IF output to the aligner's product detectors and substitutes the aligner's coherent frequency sources for the TRC-97's incoherent sources. The operating frequency in the alignment mode is 4880 MHz. Figure C.2a and C.2b show details of the relay switching of the signal lines from the TRC-97 to the aligner and back. In Fig. C.2a the port labeled "INCOHERENT 50 MHz IN" receives the TRC-97's 50 MHz synthesizer output that normally connects to J3A17. The port labeled "INCOHERENT 70 MHz IN" receives the TRC-97's 50 MHz synthesizer output that normally connects to J1 of the upconverter A17A4. The remaining signal lines and ports are self-explanatory and should be followed in installing the aligner with the TRC-97.

When the align-nonalign switch is in the nonalign position or when the aligner is powered-off the TRC-97 is returned to its normal configuration.

Step-by-Step Operating Procedure for Skew Method

1. Test the aligner's microprocessor by depressing the "test" pushbutton. The display should read 019(-2) which represents the decimal number 19×10^{-2}. If it reads correctly proceed to step 2.

2. With the aligner installed according to the preceding description and the align-nonalign switch in the align position the tropo signal should be acquired following the standard procedures outlined in the TRC-97 instruction manual. If desired, the inphase and quadrature outputs from the back panel of the aligner can be displayed on an oscilloscope to aid in visualizing received signal strength.
3. With both antennas focused the aligner should be placed in the clock mode by depressing the front panel pushbutton labeled "clock." The displayed average frequency, $\bar{\omega}$, should then be set to zero with the front panel clock frequency adjustment control.
4. With $\bar{\omega}$ set at zero the skew-estimate is made by depressing the "skew" pushbutton. The numbers displayed will vary randomly each second around an average value. (If an aircraft intrudes the common volume the skew measure will vary widely with time as the aircraft Doppler varies. The "reset" pushbutton will clear the memory allowing a new skew estimate to be obtained when the aircraft clears the antenna beams.)
5. When a stable skew estimate is obtained the receive antenna should be rotated about 1/2° in one direction and fixed.
6. The clock mode is again used to set $\bar{\omega}$ equal to zero.
7. The skew mode is next used to reestimate the skew. If the average value has been reduced the correct direction of antenna rotation was chosen. Continue to reset the antenna in small increments until the skew display changes sign. This is evidence that the receiving beam has gone through the symmetrical straddling beam position.
8. With the receiving beam positioned to give zero average skew, the defocuser is attached. If the skew remains zero the beams are correctly aligned. If the skew becomes non-zero proceed to step 9.

9. The transmitter and receiver beams are now swung synchronously in, say, 1/4° increments, both clockwise or both counter clockwise. An order-wire voice channel back to the transmitter is necessary to coordinate this synchronous beam swinging procedure. At each position $\bar{\omega}$ is set to zero and the skew measured. If the correct direction of rotation (CW or CCW) has been chosen, the skew measure will fall with each new increment until it reaches zero. At this point the two beams are producing a non-skewed Doppler spectrum indicating that they have met at the great-circle.
10. The receiving beam is then refocused to complete the alignment procedure.
11. It should be noted that if the incorrect direction of rotation had been chosen the skew would have increased as the beams diverged from the great-circle.

Step-by-Step Operating Procedure for the Slope Method

1. The signal should be acquired by following the standard methods outlined in the TRC instruction manual.
2. The atomically controlled 5 MHz receiver clock should be substituted for the 5 MHz quartz standard contained in the aligner. It is also assumed that the transmitter and receiver atomic standards are in zero-beat.
3. The aligner's microprocessor is tested by depressing the "test" pushbutton. The correct display is 019-2 or 19×10^{-2}.
4. Depressing the "slope" pushbutton will cause the aligner to read the slope of the crosscorrelation function of the quadrature components of the received signal. The slope will be non-zero when the antennas are misaligned.
5. The receiving beam should now be moved in azimuth about 1/2 degree and fixed.
6. The slope is remeasured. If it has decreased the antenna movement was in the correct direction.
7. Continue to increment the antenna in the direction that decreased slope until the slope equals zero.

8. The receiving antenna is next defocused. If the slope remains zero both beams are correctly aligned. If the slope becomes non-zero proceed to step 9.
9. The transmitting and receiving beams are now swung synchronously, both clockwise or both counter-clockwise in say, 1/4 degree steps. If the correct direction is chosen the slope will decrease with each increment until it reaches zero. At this point the beams are correctly aligned.
10. The defocuser is removed to complete the alignment procedure.

Suggestions For Further Study

1. Deficiency of Skew Estimation Program

For reasons that are not entirely clear, the skew algorithm displays sensitivity to clock error. As noted in the introduction this is contrary to theoretical expectations, but may be due to the fact that the Doppler spectrum is bounded by an 8 Hz low-pass digital filter. Therefore when the X(t) or Y(t) spectrum is spread by offsetting the clock, either the upper or lower edges of the Doppler spectrum are attenuated depending on whether the clock is raised or lowered in frequency from zero beat. This could induce positive or negative skew respectively. Widening the filter bandwidth should be tried as a solution to this problem.

Another factor that should be considered is the possibility that the skew programming of the microprocessor is deficient in computing the first and second derivatives of the quadrature components of the received signal. Since these signals are first quantized by an A/D converter, successive samples falling in the same level bin will yield a first derivative of zero and three successive samples in the same bin will yield a second derivative of zero. Thus, when the signal derivatives tend to be small, they may often be under estimated. Slowly fluctuating signals may therefore lead to errors in the various terms that make up the Skew

equation. This equation yields a small difference from large numbers and is therefore quite sensitive to errors associated with the various terms. See equation (19).

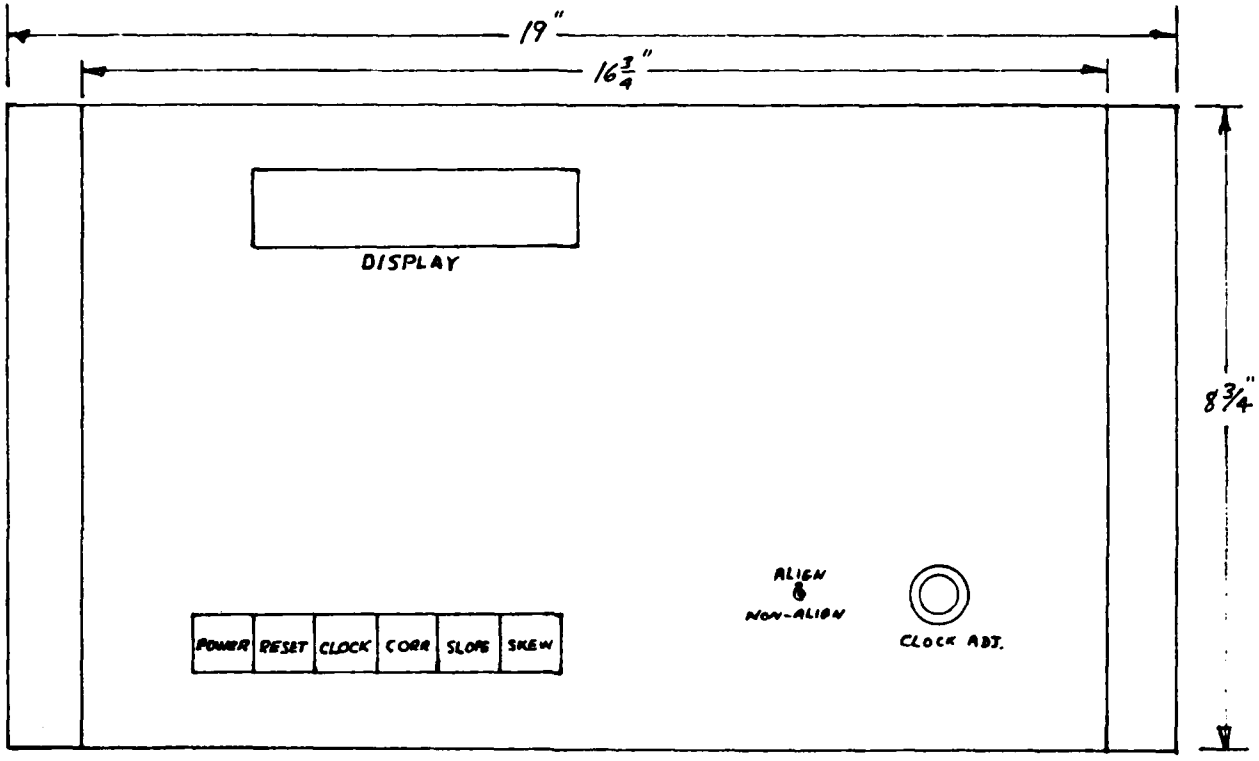
During UW tests Doppler spreads were much narrower than on the RADC link. We experienced skew estimates sensitive to clock-offset particularly when the Doppler spectrum was extremely narrow as evidenced by a zero-Doppler spike in the spectrum, suggesting the derivatives as the primary cause. The 8 Hz filter cutoff apparently was no problem on the UW link, since we were able to obtain skew estimates insensitive to clock-offset on two occasions when the Doppler spectrum was narrower than 8 Hz, but free from a specular component.

If the above two problems prove incorrect as the cause of skew sensitivity to clock offset, it might be expedient to attempt to make clock correction (to force $\bar{\omega}$ to equal zero) an automatic process. Since $\bar{\omega}$ is outputted by the slope algorithm an estimate of it could be used to correct the receiver clock by feedback to the clock control voltage input. This would remove the extra step that otherwise must be provided by the operator.

2. Additional Testing Requirements

Time permitted a fairly limited amount of testing on the RADC link. During these tests the fading rate was high and signal characteristics were consistent for the several days of the tests. Testing under a variety of signal conditions should be attempted before decisions concerning filter bandwidths are finalized.

The skew algorithm was tested only with focused beams. It is reasonable to expect the final accuracy with a defocused beam to parallel the results of the slope algorithm test, however. Nevertheless, it would be appropriate to check this when additional tests are run under different signal conditions.



Cabinet Dept: 16 3/4
Weight: 23 lbs.
Power Req: 120 VAC, 60 Hz, 2a.

Fig. 4.1 Mechanical and Electrical Specifications

APPENDIX A

MICROPROCESSOR SCHEMATICS

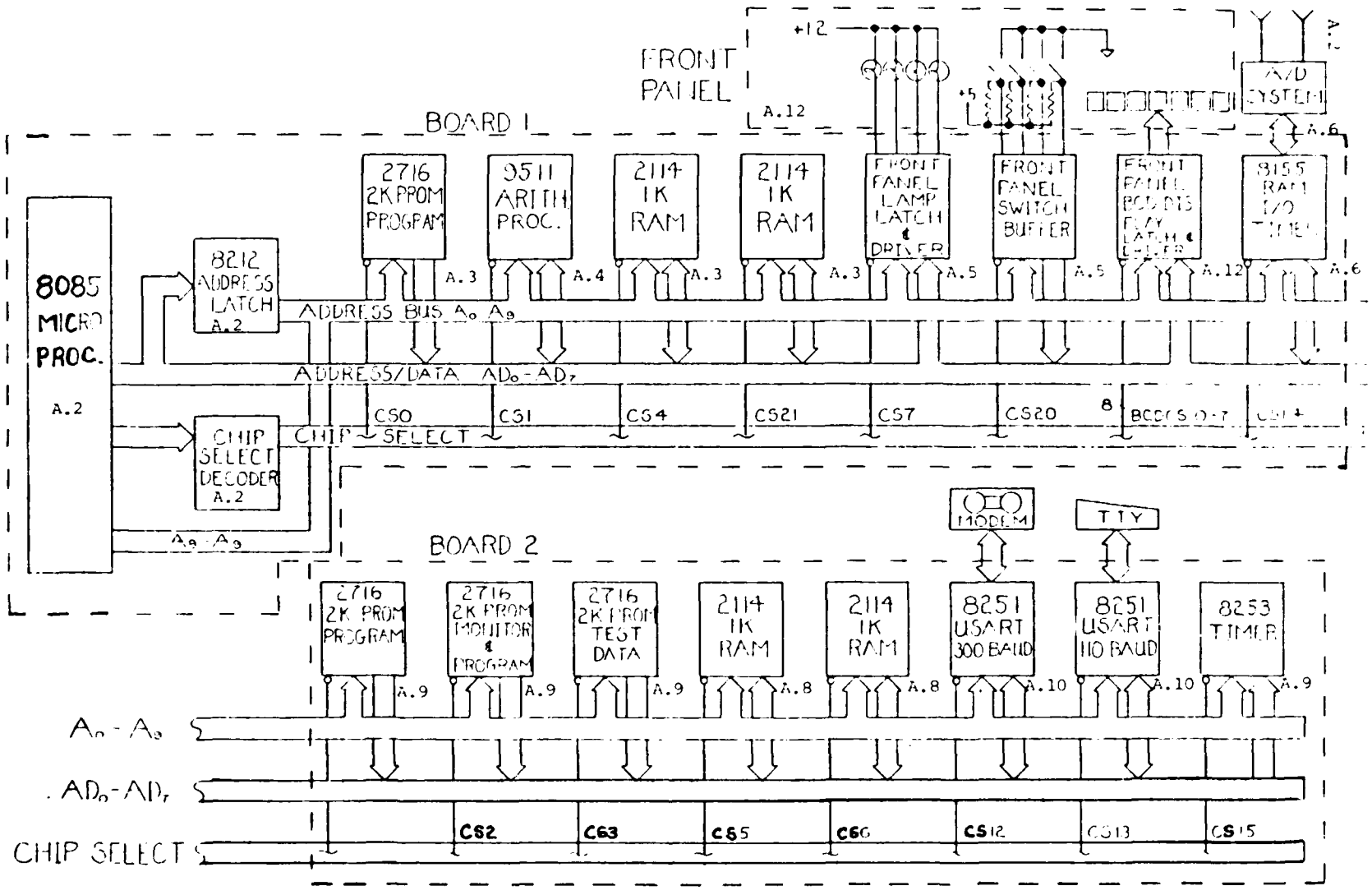


Fig.A1 BLOCK DIAGRAM OF MICROPROCESSOR SYSTEM

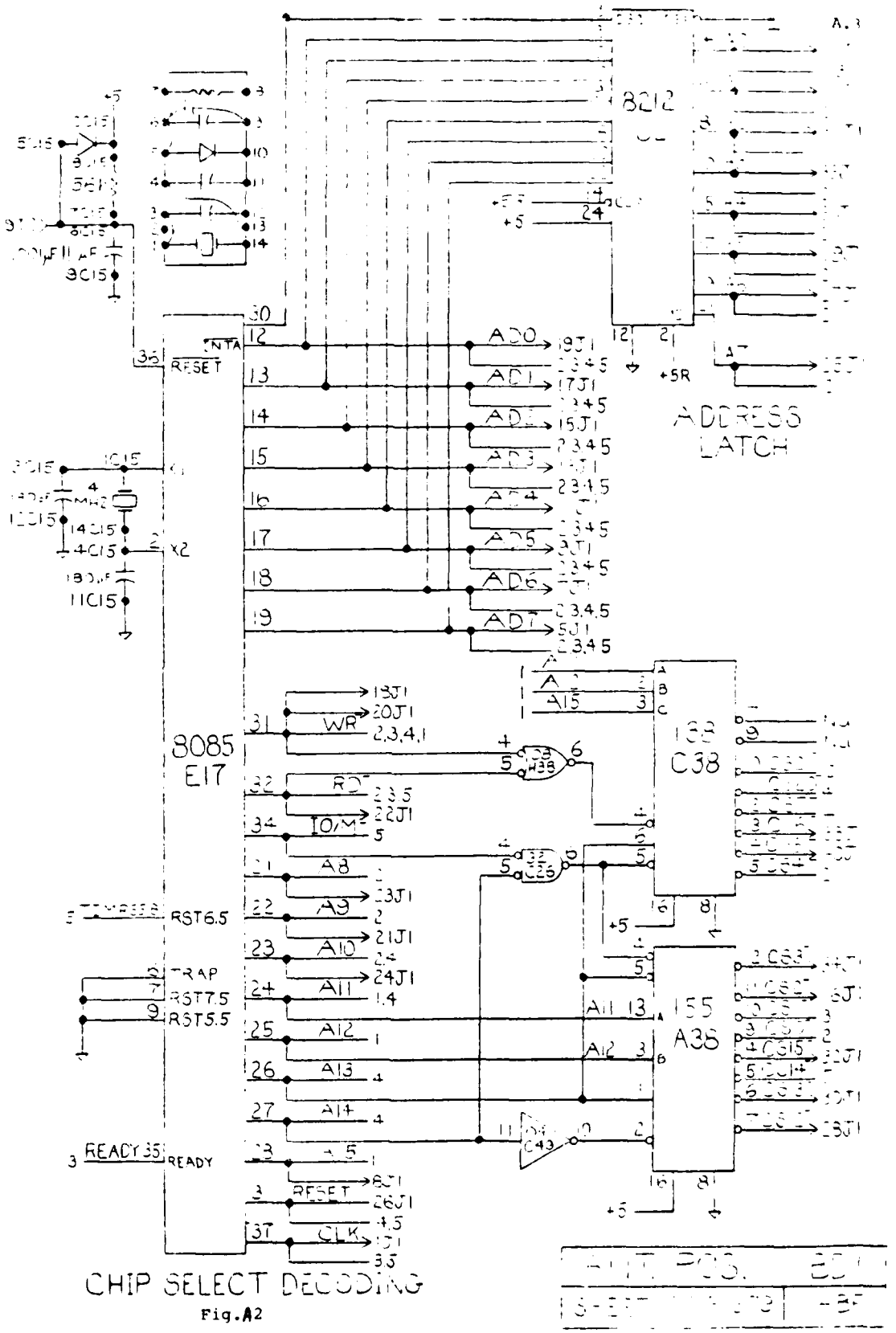

8212
ADDRESS LATCH
8085 E17
CHIP SELECT DECODING
RESET
READY
TRAP
RST7.5
RST5.5
RST6.5
INTA
WR
RD
IO/M
ALE
CLK
X1
X2
A8
A9
A10
A11
A12
A13
A14
A15
AD0
AD1
AD2
AD3
AD4
AD5
AD6
AD7
138 C38
155 A38

Fig.A2

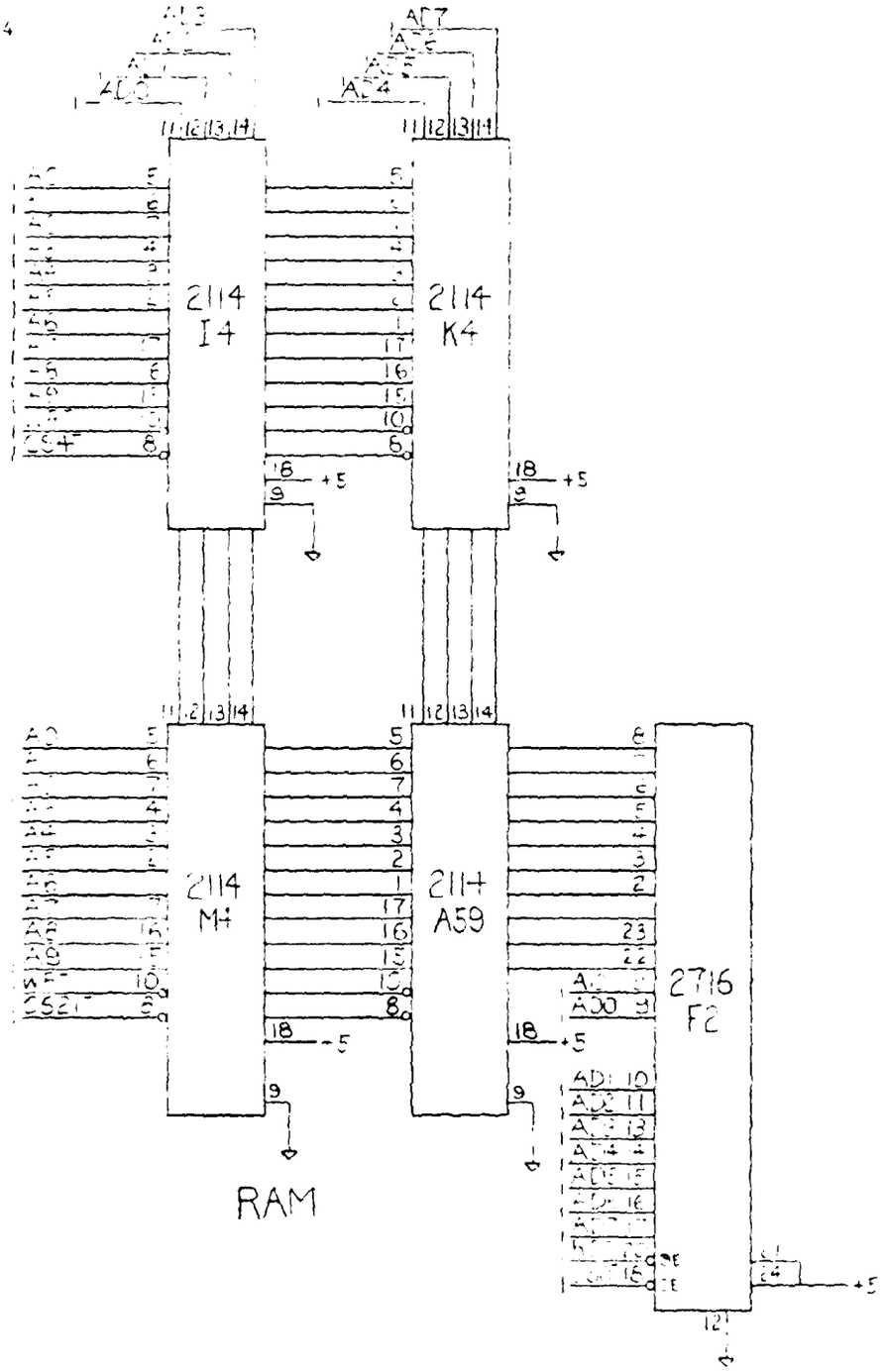
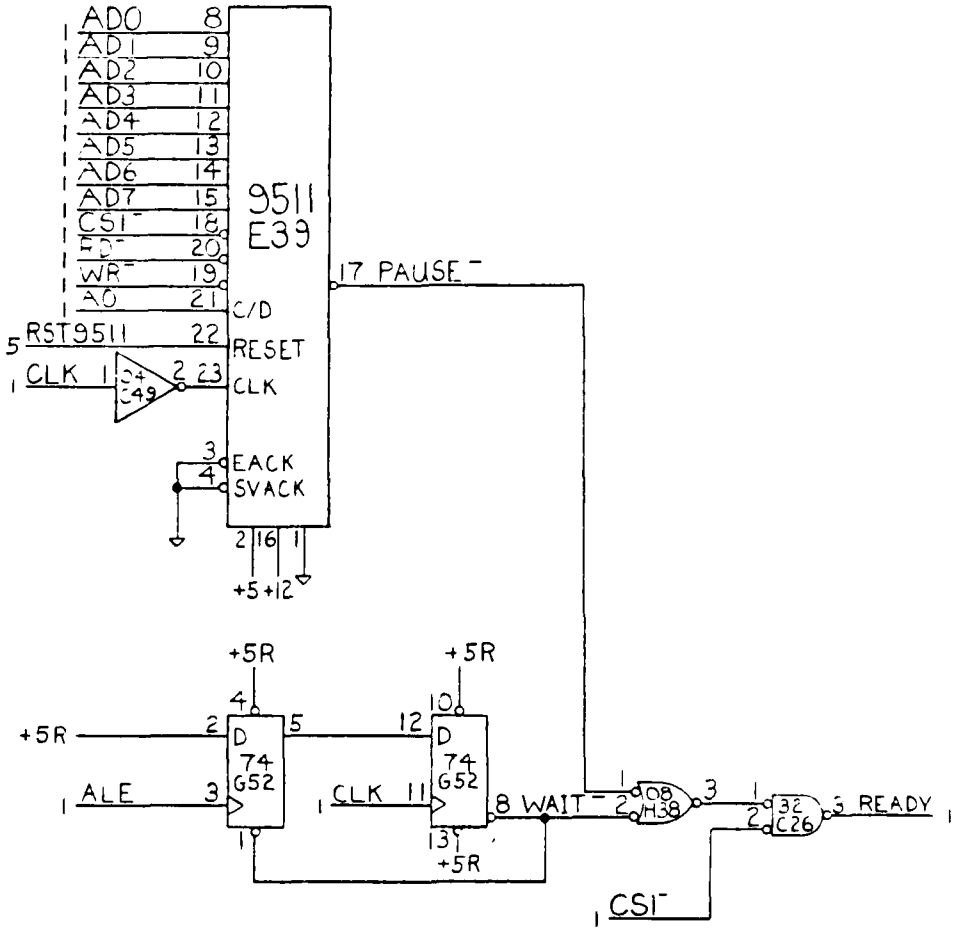


Fig. A3 PROGRAM PROM

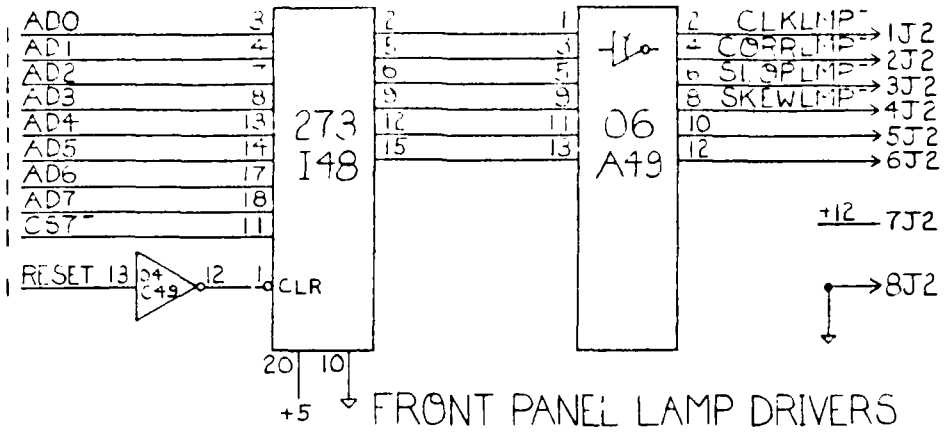
ANT. POS.	BD1
SHEET	07-03-79



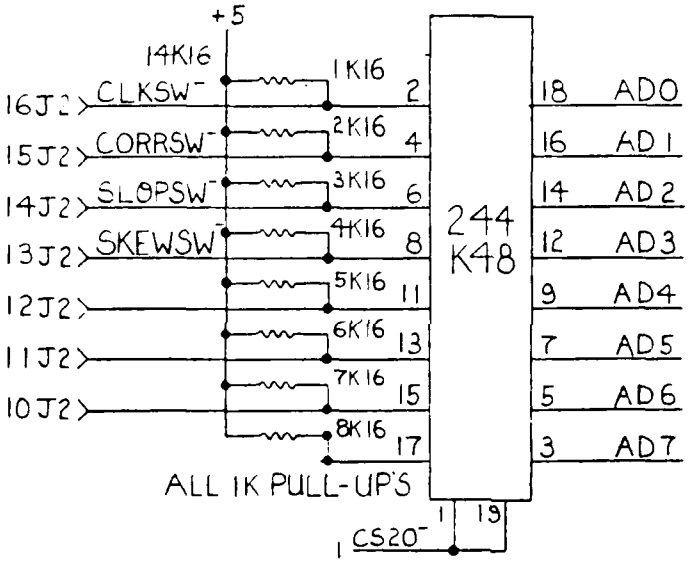
ARITHMETIC PROCESSOR AND WAIT STATE GENERATOR

Fig. A4

ANT. POS.		BD1
SHEET 3	07-26-79	ABF

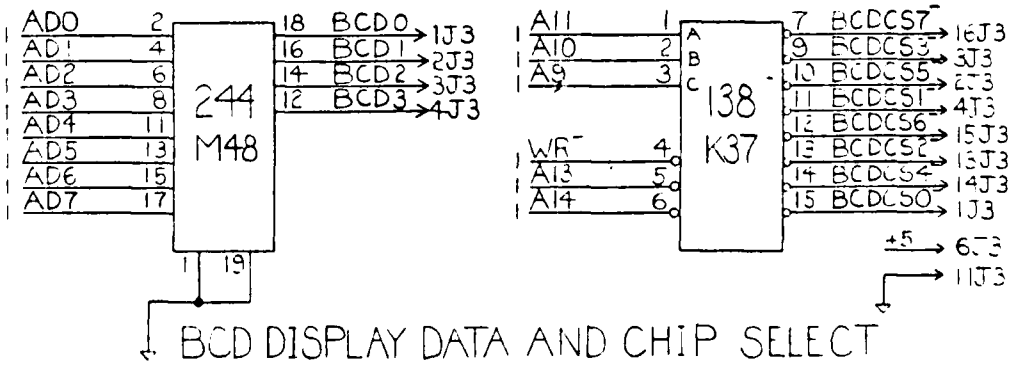


FRONT PANEL LAMP DRIVERS



ALL 1K PULL-UP'S

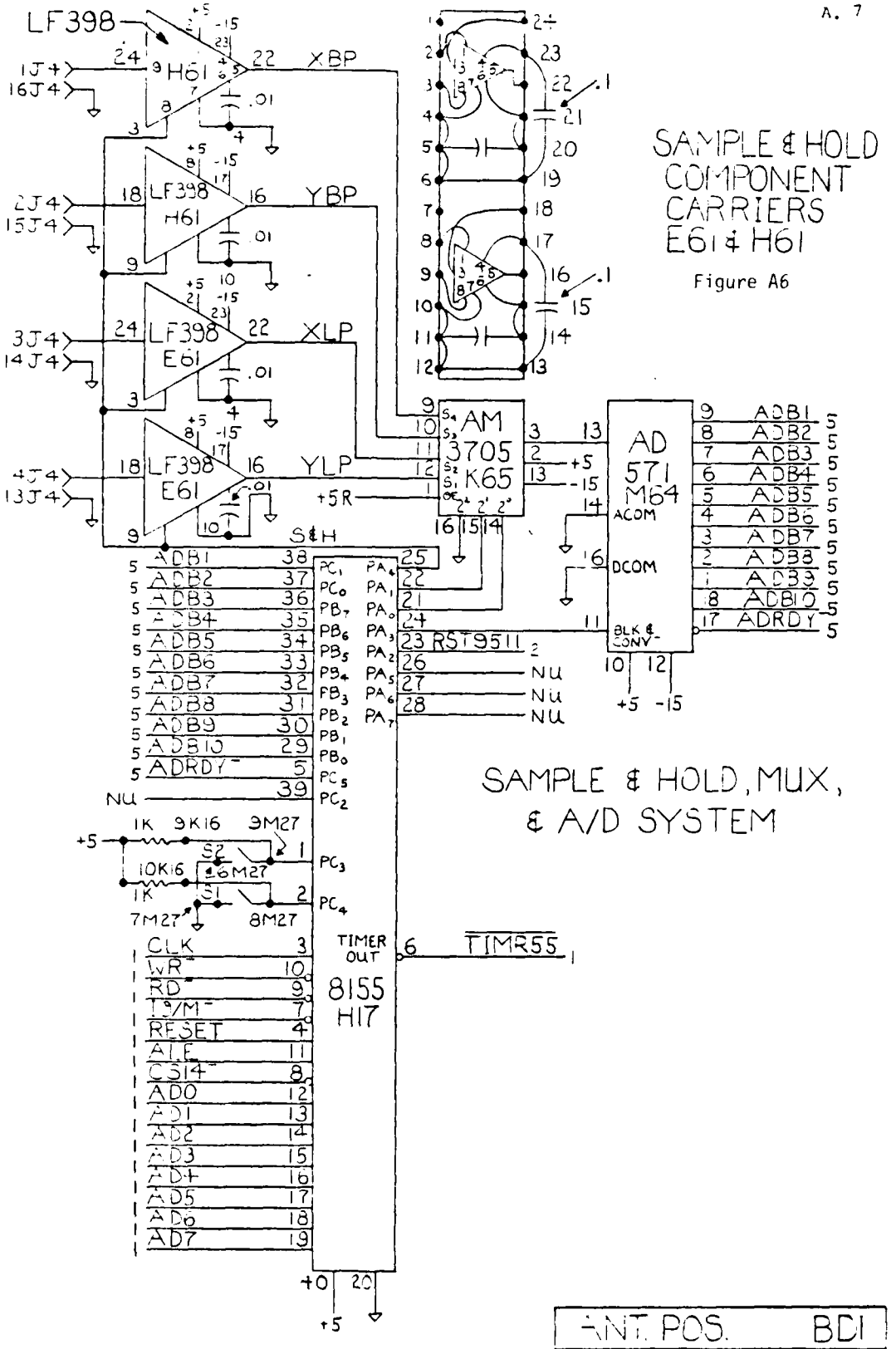
FRONT PANEL SWITCH SELECTOR



BCD DISPLAY DATA AND CHIP SELECT

Fig. A5

ANT. POS.		BDI
SHEET 4	07-23-79	ABF



SAMPLE & HOLD COMPONENT CARRIERS E61 & H61

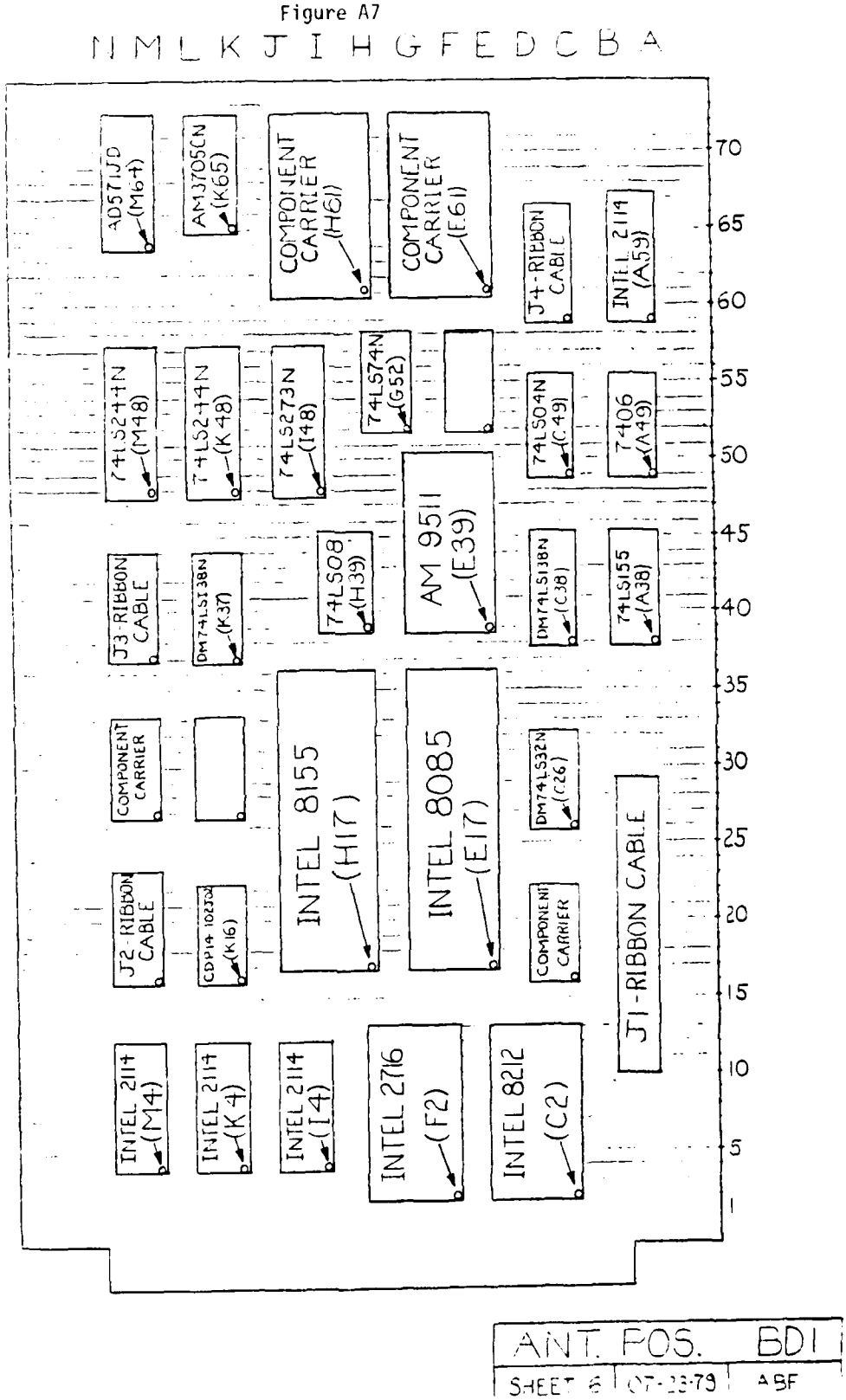
Figure A6

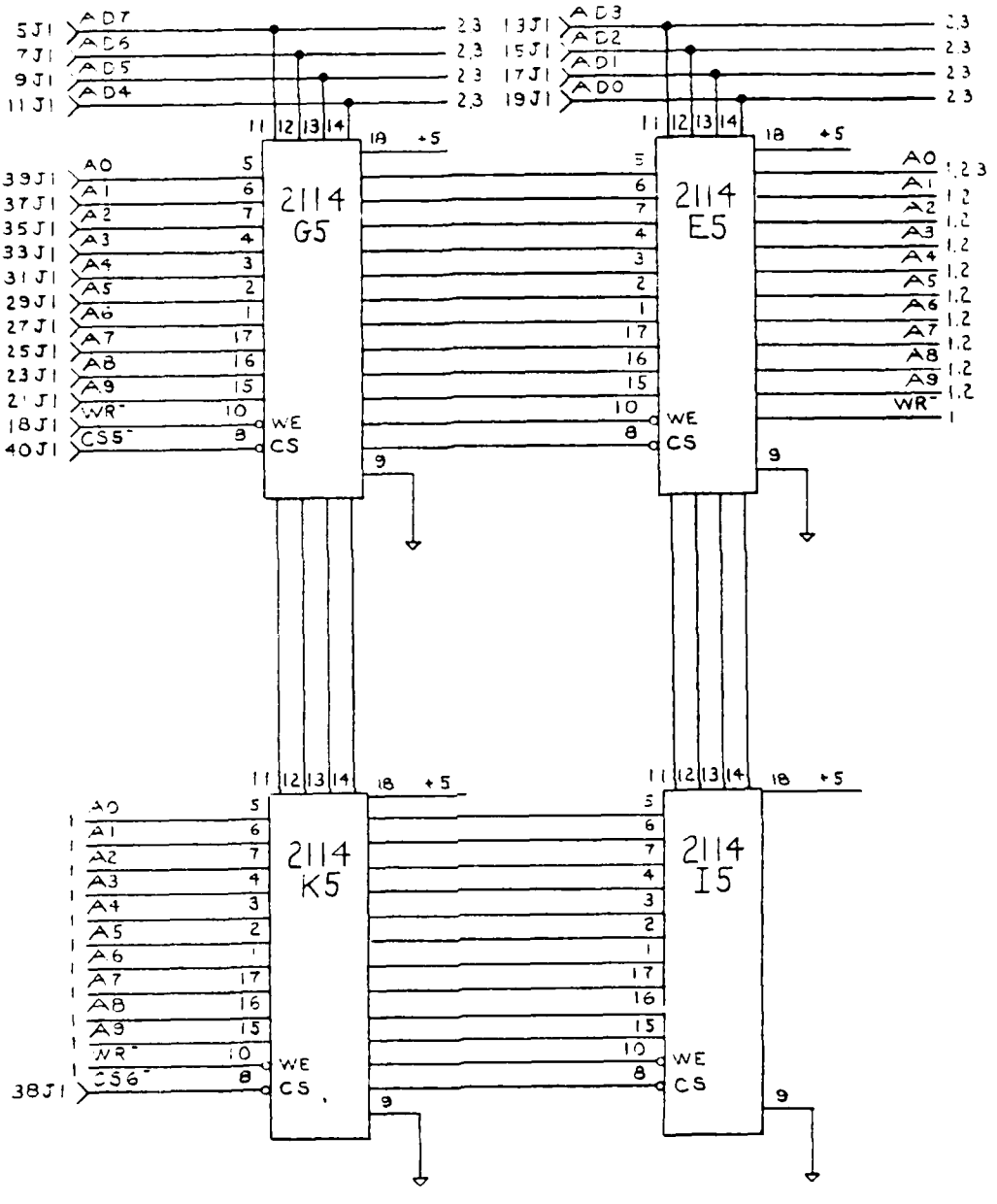
SAMPLE & HOLD, MUX, & A/D SYSTEM

ANT. POS.	BDI
SHEET 5	03-79

COMPONENTS

Figure A7





RAM

Figure A8

ANT. POS		BD2
SHEET 1	07-23-79	ABF

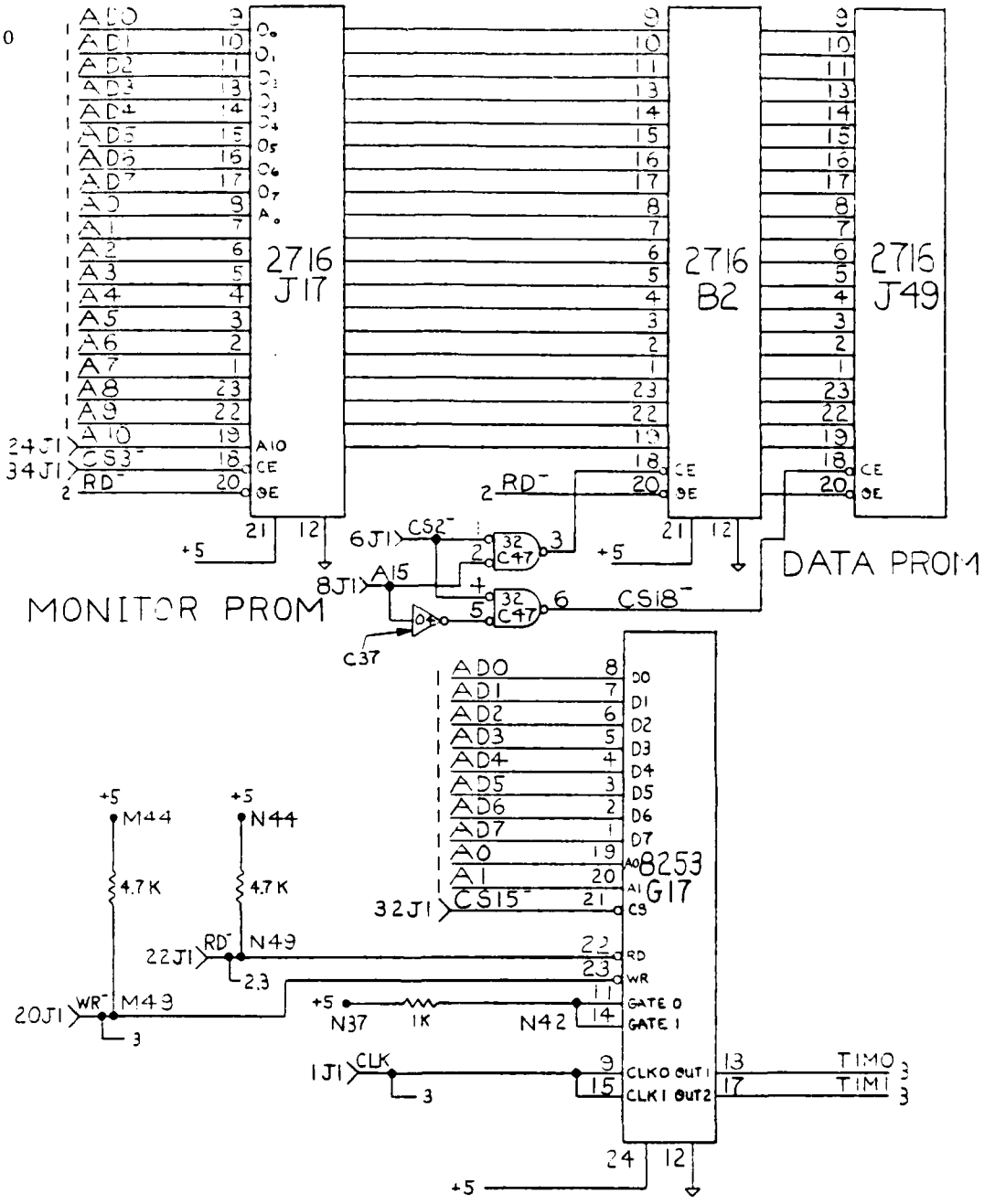


Figure A9

ANT. POS. BD2		
SHEET 2	07-23-79	ABF

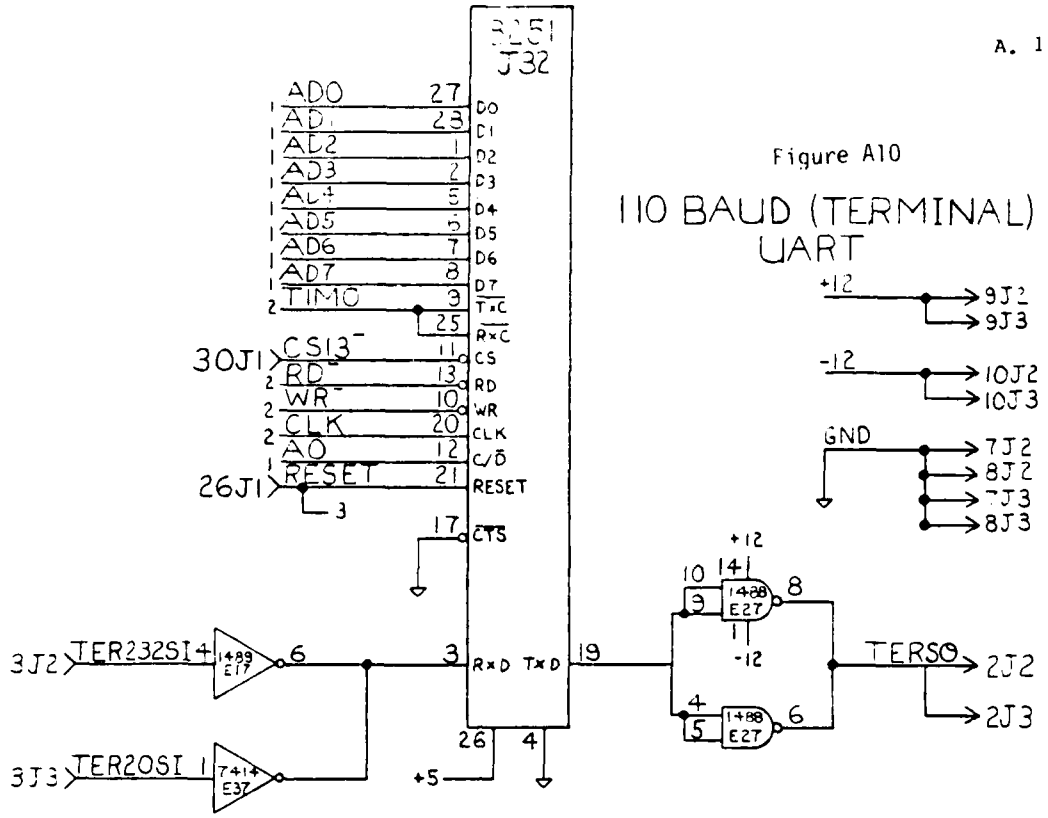


Figure A10

110 BAUD (TERMINAL) UART

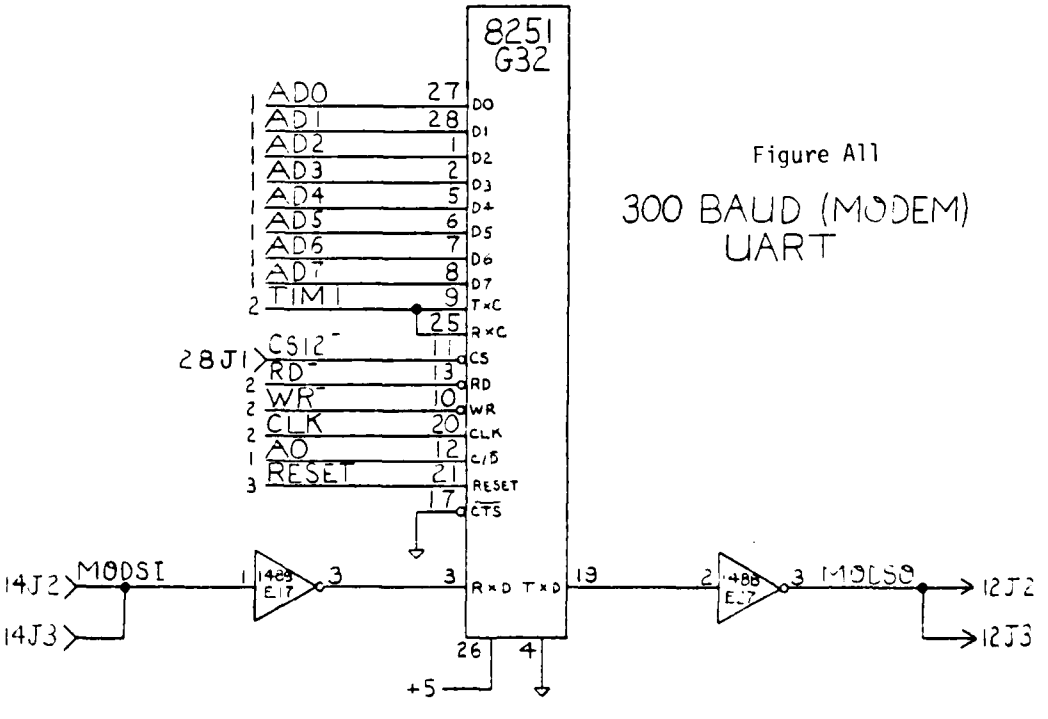
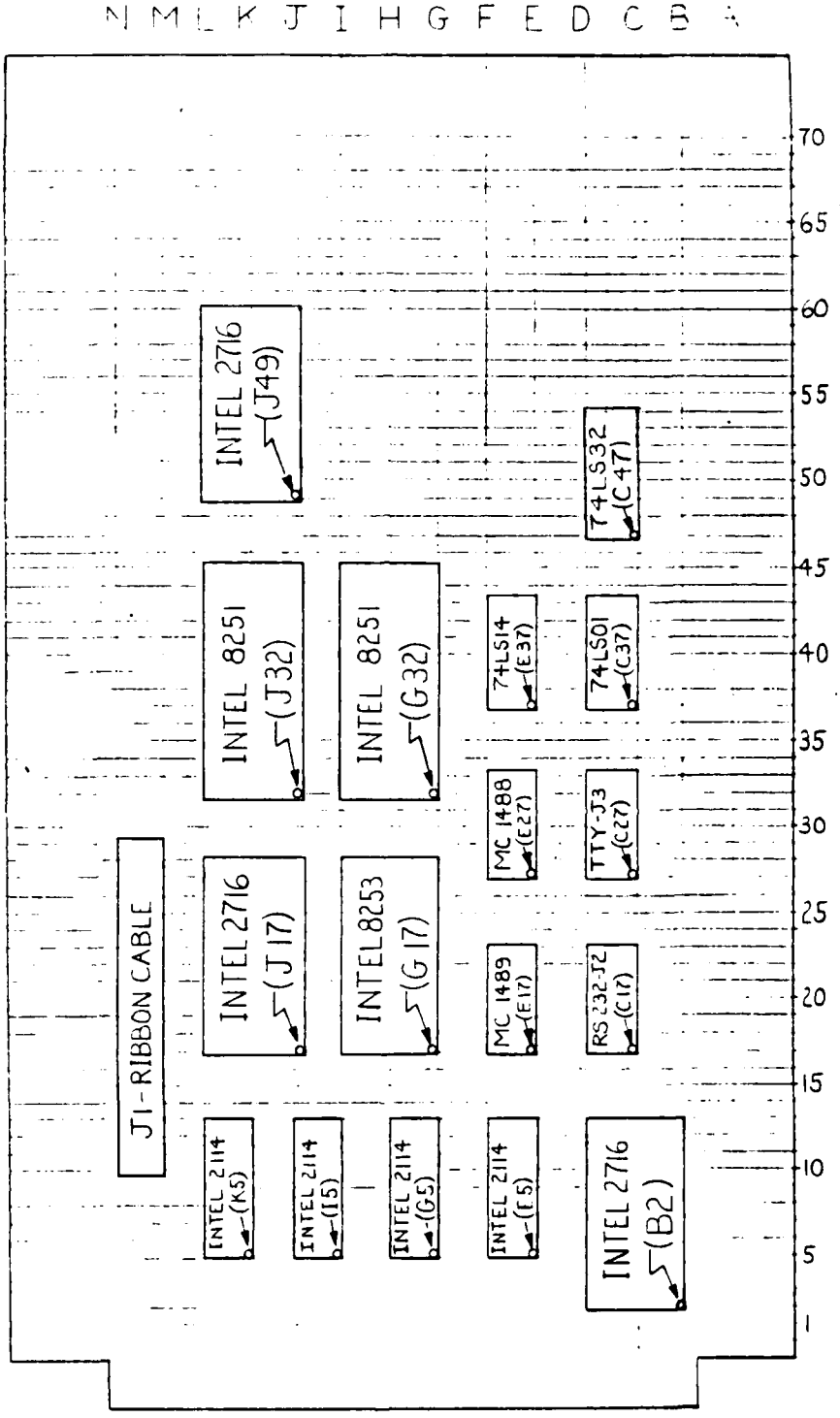


Figure A11

300 BAUD (MODEM) UART

ANT POS. BD2		
SHEET 3	07-23-79	ARF

COMPONENTS
Figure A12



ANT. POS. BD2		
SHEET 4	07-23-79	ABF

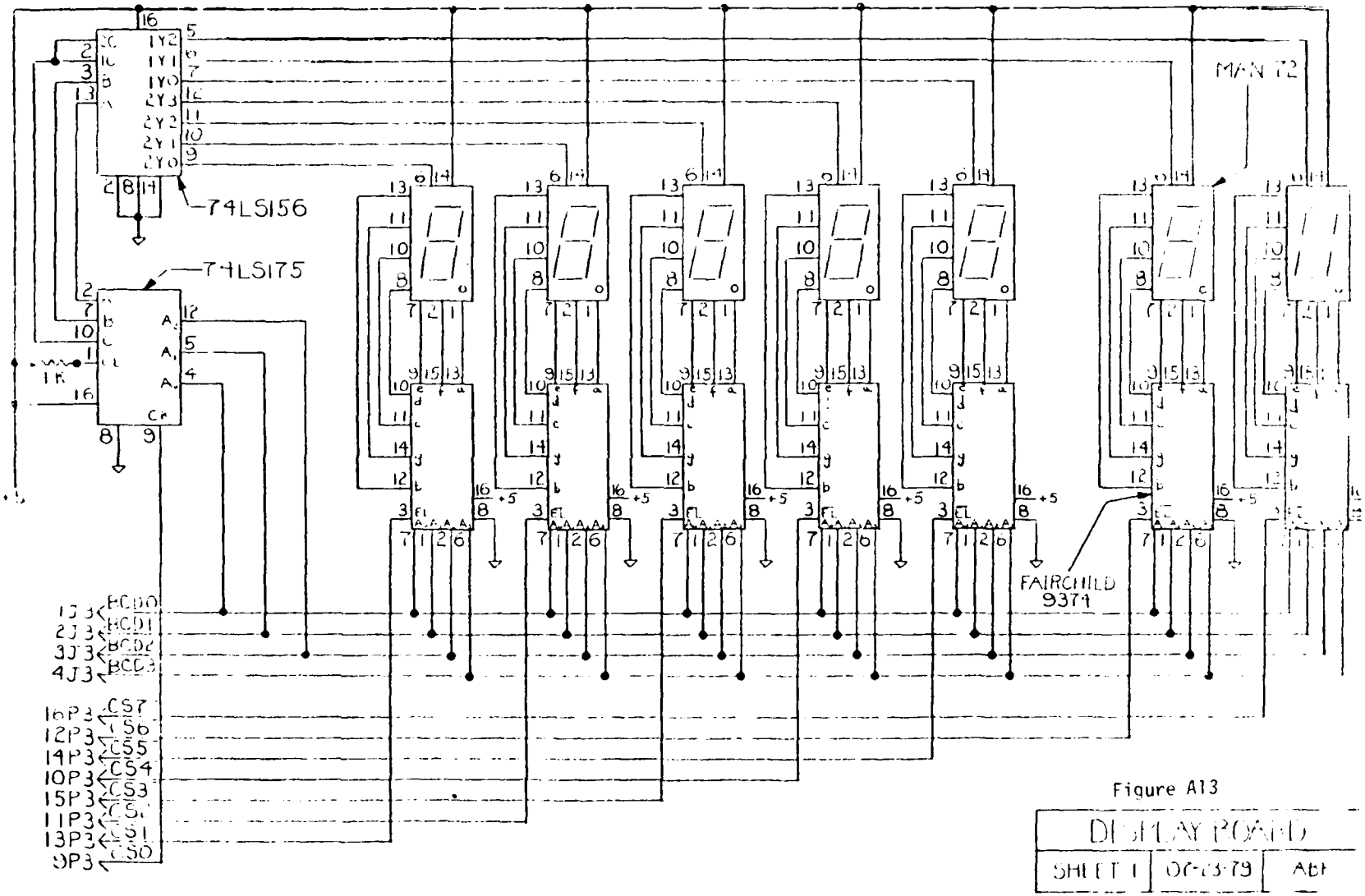

74LS156
74LS175
1K
MAN 72
FAIRCHILD
9374
BCD0
BCD1
BCD2
BCD3
CS7
CS6
CS5
CS4
CS3
CS2
CS1
CS0
DISPLAY BOARD
SHEET 1
A1

Figure A13

Parts List Microprocessor Board #1

Location	Item
M11	Intel 2114, IC
K11	Intel 2114, IC
I4	Intel 2114, IC
F2	Intel 2716, IC
C2	Intel 8212, IC
K16	CTS 760-1-R1K, Resistor Network
H17	Intel 8155, IC
E17	Intel 8085
C26	National DM 74LS32, IC
K37	National DM 74LS138, IC
H39	National DM 74LS08, IC
C38	National DM 74LS138, IC
A38	National DM 74LS155, IC
M48	National DM 74LS244, IC
K48	National DM 74LS244, IC
I48	National DM 74LS273, IC
G52	National DM 74LS74, IC
C49	National DM 74LS04, IC
A49	National DM 7406, IC
E39	American Micro AM9511, IC
K65	National AM 3705CN, IC
M64	Analog Devices AD571JD, A/D converter
A59	Intel 2114, IC
H61	National LF398, S/H IC
F61	National LF398, S/H IC
C15	56K Resistor 1/4 W, 5%
C15	4 MHz Crystal
C15	180 pF Capacitor-Ceramic
C15	1 μF Capacitor
C15	1N44 Diode
H61	.01 μF Capacitor-Ceramic
H61	0.1 μF Capacitor-Ceramic
E61	.01 μF Capacitor-Ceramic
E61	0.1 μF Capacitor-Ceramic
K16	1K Resistor 1/4 W, 5%
M27	Dip Switch 8 section, SPST

Parts List Microprocessor Board #2

K5	Intel 2114, IC
I5	Intel 2114, IC
G5	Intel 2114, IC
E5	Intel 2114, IC
J17	Intel 2716, IC
G17	Intel 8253, IC
E17	Motorola MC1489, IC
E27	Motorola MC 1488, IC
J32	Intel 8251, IC
G32	Intel 8251, IC
E37	National DM74LS14, IC
C37	National DM74LS01, IC
C47	National DM74LS32, IC
J49	Intel 2716, IC
N42	1K Resistor 1/4 W, 5%
M49	4.7 K Resistor 1/4 W, 5%
N49	4.7K Resistor 1/4 W, 5%

Parts List Microprocessor Display

1 - National DM74LS156, IC
1 - National DM74LS175, IC
7 - Monsanto MAN72, Display
7 - Fairchild 9374, IC

Power Supplies

±15 Volt, 100 mA Power Mate MD15A

+ 5 Volt, 6 A Power Mate ETR-142E

APPENDIX B - MICROPROCESSOR PROGRAMMING

Contents

Program Name	Description	Memory Locations (8085 (hexadecimal)	Pages for FORTRAM Program	Pages for 8085 Program
MAIN	1) Input data (from tape if FORTRAN; A/D or PROM in 8085) 2) Pass x,y data samples to other routines PROCESS, DISPLY, UPDATE, etc.	9039-9069	B.2-3	B.17-18
PROCESS	Process an xy data sample and accumulate averages for 1 sec. Includes: 1) Test of xy data sample for minimum signal value 2) Derivative calculations $\dot{x},\dot{y},\ddot{x},\ddot{y}$ 3) One second averages for correlation, skew, and slope variables	00A3-043A	B.4-6	B.59-65
DISPLY	Convert long term average of correlation, skew, and slope variables to a form suitable for display	94A1-9677	B.6-7	B.26-29
INITIAL	*Initialize all system variables and parameters*	925D-929B	B.7-8	B.23
UPDATE	Add one second averages of alignment variables formed in the routine PROCES to long term averages	043B-0703	B.8-11	B.66-72
STARTUP	*Program begins here after a manual reset*	0000-00A0	N.A. (not applicable)	B.57-59
ASCHED	Schedules 8085 routines: A/D every 1/100 sec. Front panel scan every 1/10 sec. Display update every sec.	908D-90D0	N.A.	B.18
RDFRNT	Scan front panel switches	90D1-9128	N.A.	B.19
ATOD	Input analog data	912B-925C	N.A.	B.20-23
DISBCD	Convert a floating point number to BCD format and display it	92F3-93FF	N.A.	B.23-26
	Debugging monitor used for program development	1800-1CB5	N.A.	B.31-48
	9511 Arithmetic routines	1CB6-1D33	N.A.	B.48-50

```
C   RADC  10/17/79 (PREVIOUS 10/16/79)
C  ANTENNA ALIGNMENT AND CLOCK OFFSET PROCESSING
C
C  A. K. FONTAINE
C
C  INPUT DIGITIZED DATA FROM UNIT 11
C
C  FEATURES:
C     ABILITY TO ENABLE/DISABLE CROSS SLOPE AND SKEW CORRECTIONS
C     ADD FALSE VARIABLE FOR DEBUGGING USES SYSTEM AND CHANGES MADE TO
C       THE ARITHMETIC THAT EXISTED ON 07/17/79.
C     MOST PROCESSING CHANGED TO FLOATING POINT.
C     CROSS, SLOPE, AND SKEW LOGICAL VARIABLES ADDED.
C     CHANGE FIRST AND SECOND DERIVATIVES TO HAMMING FOR SIG. SAVE 5 VALUES OF
C       X AND Y AND COMPUTE DX, DDX ETC. AT CENTER OF ARRAY.
C     CHANGE THETA LIMITS TO +-1200 (6 HZ)
C
      INTEGER BUFX,BUFFER(2048),DWNSAM,HEADER(60),EOF,EOFFLAG
      INTEGER JDEXP,JDSEXP,FREXP,TIME,UPTIME,VALDXY
      INTEGER JDOWNS,NTELMS,MXPRIM,NTRNTR,VALDDC
      LOGICAL CROSSA, SLOPEA, SKEWA, TRACE
      COMMON /SIMPARM/BUFFER,CROSSA,EOF,EOFFLAG,NUMBER,NREQURD
     .  ,NUMFILE,SKEWA,SLOPEA, TRACE
      COMMON /CLMPARM/ DLZN
     .  ,NDEXP,JDSEXP,DISPSN,FMAX,FREQ,FREQSN,FREXP1
     .  ,GRAFIC,MINSIG
     .  ,MAXDLE,MAXDSE,MXFRM,MASKE,MALEFT
     .  ,SAMPLER,THETA,TIMEVAL
     .  ,THETAN,TIME,WOF,UPTIME,VALDXY,XA,XAVE,XDIFFW
     .  ,XLE,YLE(3),XX,XXNEXT,YAVE,YDIFFW,YNEXT,YLE,YLE(3),YY,YYNEXT,ZSUMIN
      COMMON /CROSSPARM/ DOWNS,CLTIME,ISAMPLE,FREQ(3),FRMEW,SCALE,TIMME
     .  ,FX(50),MXPRIM,X(100),XY,YMIN,VALDDC
      COMMON /SLOPEPARM/ SLOPE,SLPNEW
      COMMON /SKEWPARM/DDXDY,DDXDYN,DXDX,DXDXN,DYDY,DYDYN
     .  ,M5,M12,M15,M16,SKEW,SKEXP,SKN
      DATA CROSSA,EOFFLAG,INPUT,SLOPEA,SKEWA
     .  /.FALSE.,0,11,.FALSE.,.FALSE./
      DATA FMAX,SAMPLER/8,100/
      DATA DOWNS/3/
      DATA M12,M15,M16,SKEW/0.,0.,0.,0./
C
C ==> SELECT BEGINNING FILE
C
  130 WRITE(1,140)
  140 FORMAT(' RADC 10/16/79'
     .  // SSO TRUE WILL RESET AFTER CURRENT BUFFER IS PROCESSED'
     .  // SSX TRUE WILL PROCESS ENTIRE FILE, FALSE WILL GO 5 BUFFERS
     .  // SSZ TRUE WILL SUPPRESS DETAILED TRACE PRINTOUT
     .  // ENTER SAMPLERATE AND BEGINNING FILE NUMBER (1, 2, ETC.)'
     .  / NUTM (INTEGER) )
      CALL FFI(ITEMP,NUMFILE)
      SAMPLER=ITEMP
      IF(NUMFILE.LE.0)GO TO 130
      NUMFILE=NUMFILE-1
      CALL AMOVE(NUMFILE,NFILE(1))
      WRITE(1,145)
  145 FORMAT(  ENTER THE 'DOWN SAMPLE' FACTOR 1, 2, 3, ETC. (1, FACTOR'
     .  'IS NO'// (THEN EVERY NTH RAW DATA POINT WILL BE USED')
      CALL FFI(DWNSAM)
      SMPLER=SAMPLER/DWNSAM
      WRITE(1,147)
  147 FORMAT(' SELECT ALGORITHMS CROSS, SLOPE, OR SKEW. ENTER 1 OR 0'
```

```
*     FOR EACH (*=TRUE ?=FALSE)
      CALL KEY(IA1,IA2,IA3)
      IF(IA1.EQ.1) CLOSE=.TRUE.
      IF(IA2.EQ.1) SLOPE=.TRUE.
      IF(IA3.EQ.1) SNOW=.TRUE.
C
C ==  LOOP HEADER
C
  150 CALL READ(HEADER,1024,IREC,IERR,NWORDS,EOF)
      IF(EOF.EQ.1 .AND. EOFFLAG.EQ.1)CALL EXIT
      EOFFLAG=0
      IF(EOF.EQ.1)EOFFLAG=1
      IF(NWORDS.NE.0)GO TO 152
        NUMFILE=NUMFILE+1
        CALL INITAL
        WRITE(3,151)
  151   FORMAT(' FILE  REC   XDC    YDC     PREC SLOPE AREAL RSLOP
     *       SNOW      P16       P12       P15 ')
C
C ==  INPUT DATA
C
  152 CALL READ(BUFFER,2048,INPUT,NWORDS,EOF)
      IF(EOF.EQ.0)GO TO 210
        EOFFLAG=1
        WRITE(3,110)
  110   FORMAT(' EOF DETECTED, MOVING TO NEXT FILE ')
        GO TO 150
C
C ==  PROCESS THIS BUFFER
C
  210 INCDATA=NWORDS/4
      DO 300 BUFFX=1,2048,INCDATA
C       TRACE=.TRUE.
C       IF(ISENSE(2).EQ.1) TRACE=.FALSE.
C
C X AND Y REVERSED!!!
C
        Y=BUFFER(BUFFX)
        X=BUFFER(BUFFX+1)
        IF(TRACE)WRITE(3,220)BUFFX,X,Y
  220   FORMAT(2X,2I7,'  BUFFX=',I5,'  X=',F10.2,'  Y=',F7.2)
        TIME=TIME+1
        TRACE=.FALSE.
        IF(TIME.EQ.0)TIME=1 TRACE=.TRUE.
         IF(ISENSE(2).EQ.1) TRACE=.FALSE.
        CALL PROCES
        IF(TIME.NE.UPTIME) GO TO 300
          CALL UPDATE
          CALL DISPLY
          TIME=0
  300   CONTINUE
      CALL DISPLY
      RECORD=RECORD+1
      ITEMP=RECORD
      IF(ISENSE(0).EQ.1) CALL INITAL
      RECORD=ITEMP
      IF(ISENSE(1).EQ.1) GO TO 200
        IF(RECORD.LE.5) GO TO 200
  320     CALL REMOVE 1,INPUT,1)
          EOFFLAG=1
          GO TO 150
      END
```

```
:F
      SUBROUTINE PROBES
C
C  PROCESS ONE X,Y SAMPLE OF DATA
C
      INTEGER BUFFX,BUFFER(2048),BUFSIZ,MEMBER,OUTPUT,BUFFLNG
      INTEGER DLEXP1,USEXP1,REXP1,TIME,UPTIME,VALDXY
      INTEGER COUNTS,PROBES,PRNTR,TRACE,VALDCC
      LOGICAL CROSSF,SLOPEA,SKEWA,TRACE
      COMMON /ERRARR/BUFFX,BUFFER,CALLSIZE,BUFFLAG,MEMBER,PRECOND
     .  ,NUMFILE,SKEW,SLOPEA,TRACE
      COMMON /COMPARM/DLEN
     .  ,DLEXP1,USEXP1,DISPCN,FMAX,PREQ,PREGEN,PREXP1
     .  ,GRATIO,MINSIG
     .  ,MXDLE,MXUSE,MXPNC,MXSKE,MACEPT
     .  ,SMPLEN,THETM,THETAL
     .  ,THETAN,TIME,TWOF,UPTIME,VALDXY,X,XDC,XDCNEW
     .  ,XL,XS(3),XX,XXN,Y,YDC,YDCNEW,YDX,YDXN,YL,YS(3),YY,YYN,ZSUMIN
      COMMON /CROSSFARM/COUNTS,CUTIME,ISAMPL,N(50),RNEW(50),RATERMS
     .  ,RA(50),RXPNTR,RY(100),RYPNTR,VALDCC
      COMMON /SLOPEFARM/SLOPEA,SLPNEW
      COMMON /SKEWFARM/DDXDY,DDXDYP,DXDX,DXDXN,DYDY,DYDYN
     .  ,MSKE,PI5,PI6,SKEW,SKEWA,TSKEW
C
C  SAVE LAST 3 VALUES OF X AND Y FOR DERIVATIVE AND XX,YY CALCULATIONS
      DO 200 J=1,2
        XS(4-J)=XS(3-J)
200     YS(4-J)=YS(3-J)
C
C  SCALE X,Y
      XS(1)=(X-XDC)
      YS(1)=(Y-YDC)*GRATIO
      IF(TRACE) WRITE(3,210) XS(1),YS(1),XDC,YDC,GRATIO
210   FORMAT(' XS,YS,XDC,YDC,GRATIO=',2F9.0,3F9.2)
C
C  MAKE SURE ZSQ MEETS MINIMUM SIGNAL CONDITION
215   ZSQ=XS(2)*XS(2) + YS(2)*YS(2)
      IF(TRACE) WRITE(3,217) ZSQ,ZSUMIN,MINSIG
217   FORMAT(' ZSQ,ZSUMIN,MINSIG=',2F9.0,I5)
      IF(ZSQ.LE.ZSUMIN*MINSIG*9
      IF(.NOT. MINSIG.EQ.0) GO TO 220
        VALDCC=0
        VALDXY=0
        ISAMPL=0
        GO TO 230
C
C  MAKE SURE LAST 3 X,Y VALUES WERE VALID
220   IF(VALDXY.LT.3) VALDXY=VALDXY+1
      IF(VALDXY.LT.3) GO TO 230
C
C  CALCULATE DERIVATIVES
C
        DX=(XS(1)-XS(3))/2
        DY=(YS(1)-YS(3))/2
C
C  CALCULATE THETACHG, THE CHANGE IN POLAR ANGLE BETWEEN THIS AND THE LAST
C  DATA POINT.
        THETAL=(DY*XS(3)-DX*YS(3))/ZSQ
        IF(TRACE) WRITE(3,221) DX,DY,THETAL,THETAL,ZSQ
221     FORMAT(' DX,DY,THETAL,ZSQ,THETAL=',4F9.2,F9.0)
        IF(THETAL.GE.-THETAL .AND. THETAL.LE.THETM) GO TO 222
          VALDCC=0
```

```
          VALMAX=0
          ISAMPL=0
          GO TO 230
C
C  ACCEPT THIS AY SAMPLE
C
  222     NACCEP=NACEP+1
          XACCEW=XACCEW+XX
          YACCEW=YACCEW+YY
          XXN=XXN+XS(1)*XS(2)
          YYN=YYN+YS(1)*YS(2)
          METAN=METHNT.METHOD
          IF(NALE) WRITE(3,2221) NACCEP,XACCEW,YACCEW,XXN,YYN,METHN
 2221   FORMAT(  NACCEP=',XACCEW=',YACCEW=',XXN=',YYN=',METHN =',I5,F9.2
     .    ,2F9.0,F9.2)
C
C  CROSS CORRELATION CALCULATIONS
          IF(.NOT. CROSSA) GO TO 224
C  UPDATE SAVED VALUES OF X & Y INPUT FOR CROSS CORRELATION
          ISAMPL=ISAMPL+1
          IF(ISAMPL.NE.CODONS) GO TO 224
            ISAMPL=0
            IF(NXPNTR.LE.0) NXPNTR=50
            NX(NXPNTR)=X-XAC
            NXPNTR=NXPNTR-1
            IF(NYPNTR.LE.0) NYPNTR=100
            NY(NYPNTR)=Y-YAC
            NYPNTR=NYPNTR-1
C  DO THE CROSS CORRELATION IF THERE ARE 100 VALID SAMPLES
            IF(VALIDC.LT.100) VALIDC=VALIDC+1
            IF(VALIDC.LT.100) GO TO 224
              NTERMS=NTERMS+1
              INDEX1=NXPNTR+50
              IF(INDEX1.GT.50) INDEX1=INDEX1-50
              NX50=NX(INDEX1)
              DO 223 J=2,50
                INDEX1=NYPNTR+51-J
                IF(INDEX1.GT.100) INDEX1=INDEX1-100
                INDEX2=NYPNTR+49+J
                IF(INDEX2.GT.100) INDEX2=INDEX2-100
                NYEVEN=NY(INDEX1)-NY(INDEX2)
  223           RNEW(J)=RNEW(J)+NX50*NYEVEN
C
C  CALCULATE SLOPE PARAMETER
  224     IF(SLOPEA) SLPNEW=SLPNEW + DX*YS(2)
          IF(NALE) WRITE(3,225)SLPNEW
  225     FORMAT(' SLPNEW=',F9.0)
C
C  CALCULATE SKEW PARAMETERS
          IF(.NOT. SKEWA) GO TO 228
            DDX=(XS(1)-2*XS(2)+XS(3))
C           DDY=(YS(1)-2*YS(2)+YS(3))
            DDXDYN=DDX*DYN+DDX*DY
            DXDXN=DXDXN+DX*DX
            DYDYN=DYDYN+DY*DY
            IF(NALE) WRITE(3,226) DDX,DDXDYN,DXDXN,DYDYN
  226       FORMAT(' DDX=',DDXDYN=',DXDXN=',DYDYN= ',4F9.0)
C
C  FOLLOWING ARE USED IN BOTH SLOPE AND SKEW ALGORITHMS
  228     IF(.NOT. (SLOPEA.OR.SKEWA)) GO TO 230
            YDXN=YDXN+YS(2)*DX
            IF(NALE) WRITE(3,229) YDXN
```

```
 229      FORMAT(' XXXX=',F9.5)
C
C  -REFARE FOR THE NEXT XYY DATA POINT
 230    ZLSU=.30
        IF(ZLSU.GE.ZSUMIN)MINSIG=1
        IF(INAGE) WRITE(3,232) ZLSG,ZSUMIN,TIME
 232    FORMAT(' ZLSU=',2F5.2,' TIME=',F9.5,I5)
      RETURN
      END
:F
      SUBROUTINE DISPLY
      INTEGER BUFFX,BUFFER(2048),DWNSAM,HEADER(50),EOF,EOFFLAG
      INTEGER DCEXPT,USEXPT,PREXPT,TIME,OUTTIME,VALDCL
      INTEGER CLDWNS,NTERMS,NXPNTS,NTERMS,VALDCL
      LOGICAL CROSSA, SLOPEA, SKEWA, TRACE
      COMMON /SIMPARM/BUFFER,CROSSA,EOF,EOFFLAG,HEADER,NRECORD
     .  ,NUMFILE,SKEWA,SLOPEA, TRACE
      COMMON /COMPARM/DCZR
     .  ,DCEXPT,USEXPT,DISPLN,FMAX,FREQ,FREQLN,PREXPT
     .  ,GRAVITY,MINSIG
     .  ,MAJCLK,MZUSE,MAXPNT,MSKE,MALERT
     .  ,SMPLFN,TMETA,TMETAL
     .  ,TMETAN,TIME,TWOMIN,OUTTIME,VALDCL,X,XDL,XDLNEW
     .  ,XL,XSIG,XX,XXN,YYDL,YDLNEW,YDX,YDXP,YL,YSIG,YY,YYP,ZSUMIN
      COMMON /CROSSPARM/CLDWNS,CLTIME,ISAMPLE,A(50),AMEAN(50),XPEAKS
     .  ,NXPNTS,NXPKPT,PKTL,SD,XPKMIN,VALDCL
      COMMON /SLOPEPARM/SLOPE,SLPMEW
      COMMON /SKEWPARM/DDXDT,DDXDTP,DXDX,DXDXP,DYDT,DYDTM
     .  ,MSKE,PI2,PI5,PIE,SKEW,SKEXPT,SKLN
      DIMENSION XTEMP(50)
      DATA CSLOP,PLAK/0.,0./
      IF(.NOT. CROSSA) GO TO 305
        AMAX=A(1)
        AMIN=AMAX
        JMAX=1
        JMIN=1
        DO 300 J=1,50
          XTEMP(J)=A(J)/XX
          IF(.NOT. (A(J).GA.AMAX)) GO TO 290
            AMAX=A(J)
            JMAX=J
 290      IF(.NOT. (A(J).LT.AMIN)) GO TO 300
            AMIN=A(J)
            JMIN=J
 300      CONTINUE
        XPEAK=AMAX
        JPEAK=JMAX
        IF(.NOT. (AMIN.GR.AMAX)) GO TO 301
          XPEAK=AMIN
          JPEAK=JMIN
 301    XPEAK=XPEAK/XX
        CONSLP=PI*ZMAX/(JPEAK*DCLTIME)
C
 305  ANSLOP=SLOPE/XX
C
C  CALCULATE SKEW MEASUREMENT
      IF(.NOT. SKEWA) GO TO 308
        DEDT=(DXDX*DYDT)/2.5
        PI2=DEG/XX
        PI5=YDX/XX
        PI5=DXDT/XX
        PIIPI2=PI*PI2
```

```
      CM2=P12*(P10*P16)
      CE=-P15*P11*P12
      SNEW=TEMP1*P15*CM2
C
 308  CONTINUE
      WRITE(3,310)NUMFILE,NRECORD,XDC,YDC,FREQ,WNSDFT,XPEAK
     .  ,CORSLP,SNEW,P10,P12,P15
 310  FORMAT(1X,2F5.0,F9.5,F6.2,F6.3,F6.0,4F7.2)
      IF(CROSSA) WRITE(3,315)(TEMP1(I),I=1,50)
 315  FORMAT((5X,10F8.3))
      RETURN
      END
:F
      SUBROUTINE INITIAL
C
C  INITIALIZE ALL SOFTWARE VARIABLES AND BUFFERS
C
      INTEGER BUFFX,BUFFER(2048),DWNSAM,HEADER(60),EOF,EOFFLAG
      INTEGER DCEXPT,DSEXPT,FREXPT,TIME,UPTIME,VALDXY
      INTEGER CCDWMS,KTERMS,KAPNIN,KTEPIN,VALDCC
      LOGICAL CROSSA, SLOPEA, SNEWA, TRACE
      COMMON /SIGNAL/BUFFER,CROSSA,EOF,EOFFLAG,HEADER,NRECORD
     .  ,NUMFILE,SNEWA,SLOPEA, TRACE
      COMMON /COMPARM/DCZN
     .  ,DCEXPT,DSEXPT,DISP2N,FMAX,FREQ,FREQZN,FREXPT
     .  ,GKAPID,GNSIG
     .  ,MXDCE,MXDSE,MXFRE,MXSKE,NACEPT
     .  ,SMPLFR,THETA,THETAL
     .  ,TMEAN,TIME,WOFF,UPTIME,VALDXY,X,XDC,XDCNEW
     .  ,AL,AS(3),XX,XYN,YDC,YDCNEW,YDY,YDYN,YL,YS(3),YY,YYN,ZSUMIN
      COMMON /CROSSPARM/CCINMS,CCTIME,ISAMPLE,X(50),XNEW(50),XTERMS
     .  ,XX(50),XXPN(N,XY(100),XYPNIN,VALDCC
      COMMON /SLOPEPARM/SLOPE,SLPNEW
      COMMON /SNEWPARM/DDXDY,DDXDYR,DXDX,DXDXN,DYDY,DYDYN
     .  ,MSKE,P12,P15,P16,SNEW,SNEWP1,SN2N
C
C ==> FREQUENCY PARAMETERS
C
      FREXPT=0
      MXFRE=16
      FREQZN=1.
      FREQ=0
      THETA=0.
      THETAN=0.
      THETAL=2*3.1415*FMAX/SMPLFR
C
C ==> SLOPE DETECTION PARAMETERS
C
      DSEXPT=0
      MXDSE=16
      SLOPE=0.
      DISP2N=1.
      SLPNEW=0.
C
C ==> DC CALCULATION PARAMETERS
C
      DCEXPT=0
      MXDCE=60
      DC2N=1.
      XDC=0
      YDC=0
      XDCNEW=0
```

```
      TALNEW=0
      XX=0
      XAN=0
      YY=0
      YYN=0
      GRATIO=1
C
C **  CROSS CORRELATION PARAMETERS
C
      ISAMPL=0
      NTERMS=0
      VALDLL=0
      EXPNIA=0
      ATPNIN=0
      CUTIME=FLOAT(ICLOWNS)/SAMPLFR
      DO 175 I=1,100
  175   RY(I)=0
      DO 180 I=1,50
        RX(I)=0.
        R(I)=0.
        ANEW(I)=0.
  180   CONTINUE
C
C **  SKEW PARAMETERS
C
      SKEXPT=0
      MXSKE=60
      SK2N=1
      DUXDT=0
      DUXDTN=0
      DADX=0
      DXDXN=0
      DYDT=0
      DYDTN=0
      YDA=0
      YDXN=0
      VALDXT=0
C
C **>  MISC PARAMETERS
C
      MINSIG=0
      NALERT=0
      NRELOND=1
      TIME=0
      TWOPI=2.*3.1459
      UPTIME=SAMPLFR
      ICUMIN=100
      RETURN
      END
:F
      SUBROUTINE UPDATE
C
C  UPDATE DISPLAY VARIABLES ONCE A SECOND
C
      INTEGER BUFFX,BUFFER(2048),NNSAM,HEADER(60),EOF,EOFFLAG
      INTEGER DCEXPT,DSEXPT,PREXPT,TIME,UPTIME,VALDXY
      INTEGER ICLOWNS,TERMS,EXPNIA,ATPNIN,VALDLL
      LOGICAL CROSSA, SLOPEA, SKEWA, TRACE
      COMMON /SAMPARM/BUFFER,CROSSA,EOF,EOFFLAG,HEADER,NRECORD
     .  ,NUMFILES,SKEWA,SLOPEA, TRACE
      COMMON /COMPARM/ DCEX
     .  ,VALEXT,DSEXPT,DISPEN,FMAX,FREQ,NBEGIN,PREXPT
```

```
      *  +DRA IC(*,*)*10
      *  +MAUE*=*UBE(*,*)*(*)*E*MAUE*)
      *  +D*=LPP(*,*E*A(*,*)*AL
      *  +IME(*)*, IME(*)=WOP(*)UP(IME(*)*VAL(*)*(*)*XUL(*)XULNEW
      *  +XL(*)*.3(*)*(*)*XXNE*)(*)UL(*)UL(*)EW(*)UA(*)UY*)(*)(*)(*)(*)(*)*)(*)*)LSUMIN
       COMMON /CHESSARM/CLIMBS(LOT,ME(10,3MPL(*A(30)*RNEW(30)/RTERMS
      *  +RA(30)/RAPTIR(*)(*)(30):RTENTIR(*)ALULL
       COMMON /SLOPEARM/SLOPE(SLPNEW
       COMMON /SLOWARM/ DUXDY(*)DUXDY(*)(*)UY(*)DYDX(*)DXDY(*)DYDYN
      *  +MSNE(*)(*)P(*)(*)P(*)(*)E(*)(*)SNEW(*)SNEAR(*)(*)N2M
       DIMENSION RNE(*)(30)
C
      IF(MALE(*).EQ.0) GO TO 260
      IF(MALE) WRITE(*,*)115)
  115 FORMAT(' ****** FOLLOWING MALE IS FROM CHANGE ******')
C *** TRANSFER 'NEW' VARIABLES TO LOCAL ONES
        DO 120 I=1,30
          RNE(I)=RNEW(I)
  120     RNEW(I)=0
        DUXDY=DUXDYN
        DXDX=DXDXN
        DYDY=DYDYN
        MALE=MALE(MALE+1)
        RTERMS=RTERMS(RTERMS)
        SLPNEW=SLPNEW
        IMETHI=IMETHN
        XULNEW=XULNEW
        XXX=XXN
        YULNEW=YULNEW
        YUX=YUXN
        YY=YYN
C
C  AND ZERO THE 'NEW' ONES
        DUXDYN=0
        DXDXN=0
        DYDYN=0
        NALEP1=0
        RTERMS=0
        SLPNEW=0
        IMETHN=0
        XULNEW=0
        XXN=0
        YULNEW=0
        YUXN=0
        YYN=0
C
C **  UPDATE X AND Y DC AVERAGE
C
        IF(IMALE) WRITE(*,122)XX,YY,RATIO,XUL,YUL
  122   FORMAT(' XX,YY,RATIO,XUL,YUL BEFORE = ',4F9.0,3F9.2)
        IF(ULEXP(*).LT.MAULE) ULEXP(*)=ULE*P(*)+1
        IF(ULEXP(*).LE.(ULL*ULLN)) ULL=ULL+ULLN
        XX=XX + (XXX/MALE(*)-XX)/ULLN
        YY=YY + (YYY/MALEP1-YY)/ULLN
        RATIO=XX/YY
        XULNEW=YULNEW/MALEP1
        YULNEW=YULNEW/MALEP1
        XUL=XUL + (XULNEW-XUL)/ULLN
        YUL=YUL + (YULNEW-YUL)/ULLN
        IF(IMALE) WRITE(*,123)XX,YY,RATIO,XUL,YUL
  123   FORMAT(2X,' AFTER =  ',4F9.0,3F9.2)
C
```

```
C ==> UPDATE FREQUENCY AVERAGE
C
      IF(TRACE) WRITE(3,124) TMEIA,FREQ
  124 FORMAT(' TMEIA,FREQ BEFORE = ',2F9.2)
      IF(FREXPF.LT.MAXFRE) FREXPF=FREXPF+1
      IF(FREXPF.GE.(FREQ2N+FREQ2N)) FREQ2N=FREQ2N+FREQ2N
      TMEIA1=TMEIA/FREXPF
      TMEIA=TMEIA*(FREXPF-1.)/FREXPF
      FREQ=59*LFR*1.E6/(TMEIA/6.0E6)
      IF(TRACE) WRITE(3,1245) TMEIA,FREQ
 1245 FORMAT(12X,'AFTER = ',2F9.2)
C
C ==> UPDATE CORRELATION CALCULATION (USE DC TIME CONSTANT)
C
      IF(.NOT.CROSSA) GO TO 140
        IF(TRACE) WRITE(3,1247) (RNEW(IP),IP=1,50)
 1247   FORMAT(' RNEW BEFORE ',10F10.0)
        IF(FRXFRM.EQ.0) GO TO 130
          DO 125 J=1,50
            RNEW(J)=RNEW(J)/FRXFRM
            R(J)=R(J) + (RNEW(J)-R(J))/DC2N
  125     CONTINUE
  130     CONTINUE
        IF(TRACE) WRITE(3,135) (R(IP),IP=1,50)
  135   FORMAT('      R AFTER ',10F10.0)
C
C ==  UPDATE SLOPE AVERAGE
C
  140   IF(.NOT. SLOPEA) GO TO 150
        IF(TRACE) WRITE(3,143) SLOPE,SLPNEW
  143   FORMAT(' SLOPE,SLPNEW BEFORE = ',2F9.0)
        IF(DSEXPF.LT.MAXSE) DSEXPF=DSEXPF+1
        IF(DSEXPF.GE.(DISF2N+DISF2N)) DISF2N=DISF2N+DISF2N
        SLPNEW=YDX1*SMPLFR/FACEPF
        SLOPE=SLOPE+(SLPNEW-SLOPE)/DISF2N
        IF(TRACE) WRITE(3,145)SLOPE,SLPNEW
  145   FORMAT(14X,'AFTER = ',2F9.0)
C
C ==> UPDATE SKEW AVERAGES
C
  150   IF(.NOT. SKEWA) GO TO 260
        IF(TRACE) WRITE(3,155) DUXDY,DUXDY,DXDX,DXDY,DYDY,DYDY
     .    ,YDX,YDX
  155   FORMAT(' DUXDY,DUXDY,DXDX,DXDY,DYDY,DYDY,YDX,YDX BEFORE'
     .    ,8F9.0)
        IF(SKEXPF .LT. MXSKE) SKEXPF=SKEXPF+1
        IF(SKEXPF .GE. (SK2N+SK2N)) SK2N=SK2N+SK2N
        SCALE1=SMPLFR/FACEPF
        SCALE2=SCALE1*SMPLFR
        DUXDY=DUXDY*SCALE1*SMPLFR
        DUXDY=DUXDY + (DUXDY-DUXDY)/SK2N
        DYDX=DYDX*SCALE2
        DXDX=DXDX + (DXDY-DXDX)/SK2N
        DYDY=DYDY*SCALE2
        DYDY=DYDY + (DYDY-DYDY)/SK2N
        YDX=YDX + (YDX1*SCALE1-YDX)/SK2N
        IF(TRACE) WRITE(3,160) DUXDY,DUXDY,DXDX,DXDY,DYDY,DYDY
     .    ,YDX,YDX
  160   FORMAT(45X,'AFTER ',8F9.2,' *** END OF UPDATE (TRACE *** )
C
  260 RETURN
      END
```

```
                ;  HANDLER
                ;  12/19/79
                ;  INCLUDES SCHED, TEST, KEYPAD MOD
                ;  CHANGES:
                ;  12/19  ADD MASK FOR FILTER FLAG
                ;  12/11  MOD DISPLAY MOD AT HERE
                ;  12/07  REAL TIME A/D DATA NOW IN
                ;  12/01  MOVE IO FROM ROM @ 9000
                ;  11/23  ADDED CONSTANTS AT BEGINNING
                ;  11/20  STACK USAGE CLEANED UP
                ;  11/14  MOVED INITAL HERE FROM STARTUP, AND OTHER ROUTINES FROM MISC
                ;
                ;;;
```

```
0028    59      AFOFS   EQU   28H
0038    60      AFUFD   EQU   38H
0018    61      AFLEF   EQU   18H
001A    62      AFUF1   EQU   1AH
A000    63      FPSW    EQU   0A000H  ;FRONT PANEL SWITCH ADDRESS
3800    64      FPLITE  EQU   3800H   ;FRONT PANEL LIGHT ADDRESS
0801    65      AMIMC   EQU   0801H   ;AMPEX II COMMAND/STATUS ADDRESS
0800    66      AMIMD   EQU   0800H   ;AMPEX II DATA ADDRESS
1000    67      DATA    EQU   1000H   ;DATA FROM LOCATION
0000    68      KSTART  EQU   0000H
        69 ;
        70 ;*************************************************************
        71 ;
        72 ;  BIOS RAM ASSIGNMENTS 7000-70FF
        73 ;
        74              ORG   7000H
7000    75 SCRAT:       DS    1         ;TEMPORARY STORAGE USED BY MONITOR
7001    76 CSUM:        DS    1         ;CHECK SUM FOR PHONE
7002    77              DS    3
7005    78              DS    1         ;JMP OPCOD. FOR RST 6.5
7006    79 CLKVEC:      DS    2         ;RST 6.5 JUMP ADDRESS IS STORED HERE
7008    80              DS    7
700F    81 DOUT:        DS    4         ;TEMPORARY STORAGE USED BY BCD DISPLAY ROUTINE: DISP
7013    82 TEMP:        DS    2         ;TEMPORARY STORAGE
        83 RSTARS       EQU   $         ;START OF RAM SUBROUTINE JMP TABLE
7015    84 START:       DS    3         ;JMP  7000H    JUMP INSTRUCTIONS ARE INITIALIZED
7018    85 INITIA:      DS    3         ;JMP  INITIA   IN RAM WHEN THE DIP SWITCHES ARE
701B    86 SCHED:       DS    3         ;JMP  SCHED    READY
701E    87 PROCES:      DS    3         ;JMP  PROCES
7021    88 UPDATE:      DS    3         ;JMP  UPDATE
7024    89 DISPLY:      DS    3         ;JMP  DISPLY
7027    90 FLTNX:       DS    1         ;X FILTER SELECT
7028    91 FLTNY:       DS    1         ;Y FILTER SELECT
        92 ;
7100    93   STACK   EQU  7100H        ;REMAINDER OF THIS RAM IS USED FOR THE STACK
        94 ;
        95 ;  END OF BIOS RAM ASSIGNMENTS
        96 ;
        97 ;*************************************************************
        98 ;
        99 ;    CONTENTS OF RAM 2800-28FF
       100 ;
       101 ;    THIS ENTIRE RAM IS INITIALIZED TO ZERO BY SUBROUTINE INITIAL
       102 ;
       103      ORG 2800H
       104 ;
       105 ;   DATA ARRAYS
       106 ;
2FFC   107    PX        EQU   $-4
2800   108              DS    200H
2BC4   109    PY        EQU   $-4       ;ARRAY ASSIGNMENTS NOW WILL MATCH FORTRAN
2BCE   110              DS    400H
2A54   111    K         EQU   $-4
2A58   112              DS    200H
2820   113    KXSAV:    DS    4
       114 ;
       115 ;   LOGICALS AND FLAGS
       116 ;
2824   117    LOBIT:    DS    1
2825   118    DOJ:      DS    1       ;COUNTER FOR DO LOOPS
```

```
2B26          119    CLOCKA: DS    1       ;CLOCK ADJUST AM FLAG   \  TEST
2B27          120    CROSSA: DS    1       ;CROSS CORRELATION FLAG  >  FLAGS
2B28          121    SLOPEA: DS    1       ;SLOPE ALGORITHM FLAG    /     IN THIS
2B29          122    SKEWA:  DS    1       ;SKEW ADJUSTMENT FLAG    /       ORDER !!!
2B2A          123    PRMPTR: DS    2       ;POINTER FOR PROM DATA
2B2C          124    SCHPTR: DS    2       ;SCHEDULER POINTERS (CLOCK POINTER, RESERVED, PANEL SCAN)
2B2E          125    ATODAT: DS    1       ;A/D TEST FLAG
2B2F          126    INDEXC: DS    1       ;TEMPORARY FOR TESTING PURPOSES
2B31          127    HADDIA: DS    1       ;A/D INITIALIZATION FLAG (=1 AFTER INITIALIZING)
2B32          128    UPLMG:  DS    1       ;UPLINK JUMP FLAG
2B33          129    PSCNT:  DS    2       ;PROM SAMPLE COUNTER
              130 ;
              131 ;  END OF RAM  2B00-2BFF
              132 ;
              133 ;
              134 ;*****************************************************************
              135 ;
              136 ;    CONTENTS OF RAM A800-AEFF
              137 ;
              138 ;
              139 ;     ORG 0A800H
              140 ;
              141 ;
A800          142    BUFFER: DS    2       ;TIME FROM START OF CYCLE POINTER
              143 ;
              144 ;  VARIABLES AND FLAGS OF PROBES (WRITTEN AND DISPLAY SUBROUTINES THAT USE
              145 ;  INITIALIZED TO ZERO BY SUBROUTINE INITAL
              146 ;
    A802      147 VROOS   EQU   $
A802          148    CUTIME: DS    4       ;
A806          149    CM2:    DS    4
A80A          150    CORSLP: DS    4       ;SLOPE OF CROSS CORRELATION AT ZERO DELAY
A80E          151    DCEXP1: DS    4
A812          152    DDX:    DS    4
A816          153    DDXDY:  DS    4
A81A          154    DDY:    DS    4
A81E          155    DSEXP1: DS    4
A822          156    DX:     DS    4
A826          157    DXDX:   DS    4
A82A          158    DY:     DS    4
A82E          159    DYDY:   DS    4
A832          160    FMAX:   DS    4
A836          161    FREQ:   DS    4
A83A          162    FREXP1: DS    4
A83E          163    FNEXP1: DS    4
A842          164    SED:    DS    4
A846          165    INDEX1: DS    2       ;INDEX OF LOCATION IN RX ARRAY
A848          166    INDEX2: DS    2       ;INDEX OF LOCATION IN RY ARRAY
A84A          167    ISAMPL: DS    1       ;16 BIT SAMPLE
A84B          168    XMAX:   DS    4       ;MAXIMUM, MINIMUM, AND PEAK VALUE OF INDEX IN
A84F          169    XMIN:   DS    4       ;  THE CROSS CORRELATION ARRAY
A853          170    XPEAK:  DS    4
A857          171    MINSIG: DS    1       ;MINIMUM SIGNAL FLAG: =1 WHEN ISQ  ISQMIN
A858          172    MSKE:   DS    4
A85C          173    P12P12: DS    4
A860          174    P12:    DS    4       ;P12*SQ ARE TEMPORARY STORAGE FOR DISPLY
A864          175    P15:    DS    4       ;  CALCULATIONS
A868          176    P16:    DS    4
A86C          177    RMAX:   DS    4       ;MAXIMUM, MINIMUM, AND PEAK VALUES OF CROSS
A870          178    RMIN:   DS    4       ;  CORRELATION
```

```
A874          179    XPEAK:  DS      4
A878          180    XAPMIN: DS      2       16 BIT INTEGER
A87A          181    XYPMIN: DS      2       16 BIT INTEGER
A87C          182    SCALE1: DS      4       #SCALE1,2 ARE TEMPORARY STORAGE FOR D.P.MPY
A880          183    SCALE2: DS      4       #  CALCULATIONS
A884          184    SKEW:   DS      4
A888          185    SNEXP1: DS      4
A88C          186    SLOPE:  DS      4
A890          187    TEMP1:  DS      1       #TEMPORARY STORAGE USED BY DISPLY
A891          188    THETA:  DS      4
A895          189    THETAC: DS      4
A899          190    VALOLD: DS      4
A89D          191    VALDAT: DS      1
A89E          192    WKSLOP: DS      4
A8A2          193    X:      DS      4
A8A6          194    XDC:    DS      4
A8AA          195    XS:     DS      12      #THREE 4-BYTE LOCATIONS
A8B6          196    XX:     DS      4
A8BA          197    Y:      DS      4
A8BE          198    YDC:    DS      4
A8C2          199    YDX:    DS      4
A8C6          200    YS:     DS      12      #THREE 4-BYTE LOCATIONS
A8D2          201    YY:     DS      4
A8D6          202    ZSV.    DS      4       #SAVED FOR CURRENT AT DATA SAMPLE
A8DA          203    ZLSV:   DS      4       #VALUE OF ZSV FOR LAST AT DATA SAMPLE
              204 #
              205 #  FOLLOWING ARE ALSO INITIALIZED TO ZERO BUT MUST NOT BE REPT
              206 #  IN THE RELATIVE ORDER THEY ARE HERE AS THEY ARE MOVED AS A BLOCK BY D.MOVE
              207 #  TO A TEMPORARY STORAGE AREA.
              208 #
     A8DE     209 DPBUF5   EQU  *
A8DE          210    ANEW:   DS      200D
A9A6          211    DDXDYN: DS      4
A9AA          212    DXDAN:  DS      4
A9AE          213    DXDYN:  DS      4
A9B2          214    DYDYN:  DS      4
A9B6          215    FACEPT: DS      4       #4 BIT INTEGER BUT USE 4 BYTES FOR CONVERSION TO FLOATING
A9BA          216    FTERMS: DS      4       #6 BIT INTEGER BUT USE 4 BYTES FOR CONVERSION TO FLOATING
A9BE          217    SLPNEW: DS      4
A9C2          218    THETAN: DS      4
A9C6          219    XDCNEW: DS      4
A9CA          220    XXN.    DS      4
A9CE          221    YDCNEW: DS      4
A9D2          222    YDXN:   DS      4
A9D6          223    YYN:    DS      4
     A9DA     224 DPBUF6   EQU  *
              225 #
              226 #
              227 #  TEMPORARY STORAGE LOCATIONS FOR VARIABLES THAT ARE USED BY D.MOVE. VARIABLES
              228 #  HERE MUST BE IN THE SAME ORDER AS IN DPBUF5-DPBUF6.
              229 #
     A9DA     230 TBUF5   EQU  *
A9DA          231    ANWT.   DS    200D      #TEMPORARY STORAGE OF ANEW AREA
AAA2          232    DDXDYT: DS    4
AAA6          233    DXDXT:  DS    4
AAAA          234    DXDYT:  DS    4
AAAE          235    DYDYT:  DS    4
AAB2          236    FACEPT: DS    4
AAB6          237    FNTERM: DS    4
AABA          238    SLPNPT: DS    4
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```
AAFE                  239     FMETAT: DS    4
AAL                   240     ADUMET: DS    4
AALC                  241     XYT:    DS    4
AALA                  242     TABMET: DS    4
AALE                  243     YDATI:  DS    4
AAL                   244     TTT:    DS    4
                      245 ;
                      246 ;
                      247 ;
                      248 ;   VARIABLES OF PROCESS, WINDOW AND DISPLAY THAT ARE INITIALIZED TO A
                      249 ;   NON-ZERO VALUE BY THE SUBROUTINE INITIAL.
                      250 ;
AAI                   251     JOBNO:  DB      01H,00H,00H,00H       ;1
AAJ
AAJ
AAJA                  252     DISPLN: DB      01H,00H,00H,00H       ;1
AAJE
AAJC
AAJD
AAJE                  253     FREEQN: DB      01H,00H,00H,00H       ;1
AAJF
AAK
AAK1
AAK                   254     CHARCO: DB      01H,00H,00H,00H       ;1
AAK3
AAK4
AAK5
AAK                   255     SX2N:   DB      01H,00H,00H,00H       ;1
AAK
AAK8
AAK9
                      256 ;
     AALA             257 VBUFE    EQU  $
                      258 ;
                      259 ;   END OF RAM AREA AAFE-AALF
                      260 ;
                      261 ;***************************************************************
                      262 ;
                      263 ;
     4000             264     LED1    EQU   4000H
     4200             265     LED2    EQU   4200H
     4400             266     LED3    EQU   4400H
     4600             267     LED4    EQU   4600H
     4800             268     LED5    EQU   4800H
     4A00             269     LED6    EQU   4A00H
     4C00             270     LED7    EQU   4C00H
     4F00             271     LED8    EQU   4F00H
     e501             272     SIOC    EQU   e501H
     e001             273     SIOD    EQU   e001H     ;COMMON ADDRESSES FOR UARTS
                      274 ;
                      275 ;  END OF MASTER LIST OF EQUATES, GLOBAL VARIABLES, AND RAM ASSIGNMENTS
                      276 ;
                      277 ;!!!
```

```
                        284 ;***************************************************
000D                    285         CR      EQU  0DH
000A                    286         LF      EQU  0AH
1B25                    287         ERRO    EQU  1B25H
1B39                    288         ERRSUB  EQU  1B39H              ;ERROR OUTPUT ROUTINE
1B43                    289         REVIN   EQU  1B43H              ;BEGINNING OF MONITOR
1A02                    290         CRLF    EQU  1A02H              ;CRT/NEWLINE CORDER
1A0C                    291         RESTART EQU  1A0CH
1F62                    292         FMUB2   EQU  1F62H
1F67                    293         FADD1   EQU  1F67H
1F6A                    294         FMUB    EQU  1F6AH
1F70                    295         FSUB2   EQU  1F70H
1F78                    296         FADD2   EQU  1F78H
1F7B                    297         FSUB    EQU  1F7BH
1F81                    298         FMUL2   EQU  1F81H
1F85                    299         FMUL1   EQU  1F85H
1F89                    300         FMUL    EQU  1F89H
1F8F                    301         FDIV2   EQU  1F8FH
1F94                    302         FDIV1   EQU  1F94H
1F97                    303         FDIV    EQU  1F97H
1F9D                    304         FLOAT   EQU  1F9DH
1FA2                    305         FLOATC  EQU  1FA2H
1FAD                    306         PUSH4   EQU  1FADH
1FC4                    307         POP4    EQU  1FC4H
1FF7                    308         MSINI   EQU  1FF7H
0001                    309         FLOWF   EQU  01H
0000                    310         FLOWP   EQU  00H
0003                    311         ARIOWP  EQU  03H
0002                    312         TRIGWP  EQU  02H
                        313 ;
                        314 ;
                        315 ;   FOR THE JUMP VECTOR TABLE (3 BYTES/INST MUST BE IN THE ORDER LISTED)
                        316 ;
                        317             ORG   7015H
7015 C3 3990            318             JMP   ASTART            ;ACTUAL ADDRESS OF START
7018 C3 5B92            319             JMP   AINITA            ;ACTUAL ADDRESS OF INITIA
701B C3 6D90            320             JMP   ASCHED            ;ACTUAL ADDRESS OF SCHED
                        321 ;           JMP   APROCE            ;ACTUAL ADDRESS OF PROCES
                        322 ;           JMP   AUPDAT            ;ACTUAL ADDRESS OF UPDATE
                        323 ;           JMP   ADISPL            ;ACTUAL ADDRESS OF DISPLY
                        324 ;
                        325 ; *** LAST OF LOCAL EQUATES ***
                        326 ;
                        327 ;
                        328 ;
                        329         ORG  9000H
                        330 ;
                        331 ;   MISC FLOATING POINT CONSTANTS
                        332 ;
                        333 ;
9000 01                 334         ONE:    DB      01H,80H,00H,00H
9001 80
9002 00
9003 00
9004 02                 335         TWO:    DB      02H,80H,00H,00H
9005 80
9006 00
9007 00
9008 04                 336         TEN:    DB      04H,00H,00H,00H
9009 A0
```

```
9008 00
900F 10
900C 07          337            UMEM:   DB      07H,0,5H,1,0AH,00H
900A CE
900E 00
900F 00
9010 00          338            TEN:    DB      00H,00H,00H,00H
9011 00
9012 00
9013 0A
9014 00          339            THOND:  DB      00H,00H,00H,0AH
9015 00
9016 00
9017 64
                 340 ;
                 341 ;
                 342 ;
                 343 ;   CONSTANTS USED BY PROCESS UPDATE OR DISPLAY
                 344 ;
9018 03          345            LCDWNS: DB      03H                     ;3
9019 06          346            MXDLE:  DB      06H,0F0H,00H,00H        ;60
901A F0
901B 00
901C 00
901D 05          347            MXISE:  DB      05H,80H,00H,00H         ;10
901E 80
901F 00
9020 00
9021 05          348            MXNE:   DB      05H,80H,00H,00H         ;10
9022 80
9023 00
9024 00
9025 06          349            MXSE:   DB      06H,0F0H,00H,00H        ;60
9026 F0
9027 00
9028 00
9029 07          350            SMFLFR: DB      07H,08H,00H,00H         ;100
902A 08
902B 00
902C 00
902D 00          351            TMETML: DB      00H,60H,00H,00H         ;28*188/100
902E 60
902F 00
9030 00
9031 03          352            TWOSI:  DB      03H,0E9H,00H,00H        ;2*FI
9032 E8
9033 00
9034 00
                 353            UPTIME  EQU     SMFLFR          ;UPDATE DISPLAY ONCE A SECOND
9035 07          354            ZSGMI:  DB      07H,08H,00H,00H         ;100
9036 08
9037 00
9038 00
                 355 ;
                 356 ;
9039             357 MSTART:     EQU     $
9039 3E 01       358             MVI     A,01H
903B D3 70       359             OUT     70H                     ;SET UP PROCESSOR PANEL = INPUT
903D CD 1B70     360             CALL    INITAL                  ;INITIALIZE THE SYSTEM VARIABLES
9040 CD 1B70     361             CALL    SCHED                   ;  AND THE SCHEDULER
```

```
9043 3E 01    361           MVI   A,01H             ;TEST THE SYSTEM WITH THE CLOCK RUNNING
9045 32 2E7A  362           STA   CLOCKA
9048 32 2E7B  363           STA   AIODFF            ;USING THE FROM WITH
904B CD E040  364           CALL  TEST
904E CD 1870  365           CALL  INITAL            ;RE-INITIALIZE THE SYSTEM ENVIRONMENTS
9051 CD 1A70  366           CALL  SCHED             ; AND THE SCHEDULER
9054 21 0010  367           LXI   H,TASK1
9057 22 2A7B  368           SHLD  FRMPTR            ; AND THE FROM POINTER
905A 3A 0080  369 START1:   LDA   FPSW              ; AND WAIT FOR THE OPERATOR TO SELECT
905D 2F       370           CMA                     ; THE TEST DESIRED
905E E6 0F    371           ANI   0FH
9060 CA 5A70  372           JZ    START1
9063 CD A170  373           CALL  NUMBT             ;FIND OUT WHICH TEST IT IS
9066 CD 1870  374 START2:   CALL  SCHED             ;AND PROCEED WITH THE DESIGNATED TEST
9069 C3 6690  375           JMP   START2
              376 ;
              377 ;
              378 ;*********************************************************
              379 ;
              380 ;       TEST SYSTEM WITH FROM DATA
              381 ;
              382 ;*********************************************************
              383 ;
906C 21 0010  384 TEST:     LXI   H,TASK1           ;INITIALIZE THE FROM WITH POINTER
906F 22 2A7B  385           SHLD  FRMPTR
9072 21 F401  386           LXI   H,500             ; AND THE NUMBER OF SAMPLES TO USE
9075 22 3A7B  387           SHLD  FSCNT
              388 ;
9078 CD 1A70  389 TEST1:    CALL  SCHED             ;GET AND PROCESS A DATA SAMPLE
907B 2A 3A7B  390           LHLD  FSCNT             ;ARE THERE ANY SAMPLES LEFT?
907E 2B       391           DCX   H
907F 7C       392           MOV   A,H
9080 A7       393           ANA   A
9081 C2 8790  394           JNZ   TEST3
9084 7D       395           MOV   A,L
9085 A7       396           ANA   A
9086 C8       397           RZ                      ; NO: RETURN TO CALLING PROGRAM
9087 22 3A7B  398 TEST3:    SHLD  FSCNT             ; YES: SAVE THE COUNTER
908A C3 7890  399           JMP   TEST1
              400 ;
              401 ;
              402 ;*********************************************************
              403 ;
              404 ;       SCHEDULER ROUTINE
              405 ;
              406 ;*********************************************************
              407 ;
     908D     408 RSCHED  EQU   $                 ;
              409 ;       EI
908D 2A 2C7E  410           LHLD  SCHPTR            ;GET OF THE POINTER TO WHERE YOU'RE GOING
9090 7D       411           MOV   A,L               ;SEE IF THIS IS THE FIRST CALL HERE - INITIALIZING
9091 A7       412           ANA   A
9092 C2 9C90  413           JNZ   SCH1              ;JUMP IF IT'S NOT THE FIRST TIME - TO PROCESS DATA
9095 21 6401  414           LXI   H,TASK4           ;FIRST CALL: INITIALIZE SCHEDULER'S POINTERS
9098 22 2C7E  415           SHLD  SCHPTR
909B C9       416           RET                     ;AND WAIT FOR THE NEXT CALL TO THE SCHEDULER
              417 ;
909C CD 2E91  418 SCH1:     CALL  MYDR              ;
909F CD 1E70  419           CALL  PROCES            ;PROCESS THE AT DATA SAMPLE
90A2 2A 2C7E  420           LHLD  SCHPTR            ;UPDATE THE POINTERS AND SEE IF ANYTHING ELSE SHOULD
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90A5 2B       422          DCX  H              ;  BE DONE
90A6 22 C350  423          SHLD SCN2          ;UPDATE COUNT
90A9 21 0401  424          LXI  H,0104H       ;AVERAGE TIME SHOULD BE UPDATED AND DISPLAYED, RESET
90AC 22 0E0B  425          SHLD SCNPTR        ;  THE POINTERS FIRST
90AF CD 1A70  426          CALL UPDATE
90B2 3A 0E0B  427          LDA  LEDSSA
90B5 A7       428          ANA  A
90B6 CA 90C0  429          JZ   SCN3          ;IF NOT DOING THE CORRELATION CO DISPLAY
90B9 3A 99A8  430          LDA  CALCUL        ;IF WE ARE DOING THE CORRELATIONS MAKE SURE
90BC FE 09    431          CPI  1000          ;THAT THERE IS SOMETHING TO DISPLAY
90BE F8       432          RM
90BF CD 2470  433 SCN3:    CALL DISPLY
90C2 C9       434          RET
              435 ;
90C3 2B       436 SCN2:    DCR  M             ;SCAN THE FRONT PANEL?
90C4 22 C02B  437          SHLD SCNPTR
90C7 C0       438          RNZ                ;  IF COUNT IS NON-ZERO DO NOT SCAN
90C8 26 0A    439          MVI  H,10          ;  YES, RESET THE COUNTER FIRST
90CA 22 C02B  440          SHLD SCNPTR
90CD CD D1F0  441          CALL KBFRNT        ;THEN SCAN THE FRONT PANEL
90D0 C9       442          RET
              443 ;
              444 ;**********&***********************&&&&&&&&&&&&&&&&&&&&&&&&&&
              445 ;
              446 ;        SUBROUTINE TO READ THE FRONT PANEL
              447 ;
              448 ;**********************************&&&&&&&&&&&&&&&&&&&&&&&&&&
              449 ;
              450 ;    IF A SWITCH IS NOT FOUND PRESSED SUBROUTINE RETURNS
              451 ;    IF A SWITCH IS FOUND PRESSED,
              452 ;       1) ALGORITHM FLAGS AND FRONT PANEL LAMPS ARE SET TO THE NEW CONDITION
              453 ;       2) INITIAL SUBROUTINE IS CALLED
              454 ;       3) SUBROUTINE RETURNS
              455 ;
              456 ;   LIGHTS:  SKEW  SLOPE  CORR  CLOCK
              457 ;   DATA BIT: D3    D2     D1    D0
              458 ;
    00D1      459 KBFRNT EQU  $
90D1 3A 00A0  460          LDA  FPSW          ;A <-- FRONT PANEL SWITCH STATUS
90D4 2F       461          CMA                ;INVERT SINCE SWITCHES ARE NEGATIVE TRUE
90D5 E6 0F    462          ANI  0FH           ;SWITCHES ARE IN LOWEST 4 BITS ONLY
90D7 C8       463          RZ                 ;RETURN IF A SWITCH IS NOT PRESSED
              464 ;
90D8 32 0038  465          STA  FPLITE        ;TRANSFER NEW SWITCH STATUS TO LIGHTS
90DB 32 1370  466          STA  TEMP          ;AND STORE IT WHERE INITIAL WON'T DISTURB IT
90DE E6 06    467          ANI  06H           ;SET UP FILTER SWITCHING
90E0 C2 90F0  468          JNZ  HIGHP
90E3 3E 01    469          MVI  A,FILOW       ;SELECT LOW PASS FILTERS FOR SLOPE AND CORRELATION
90E5 32 1370  470          STA  FLTKY
90E8 3E 00    471          MVI  A,FILOW
90EA 32 1B70  472          STA  FLTKX
90ED C3 90FA  473          JMP  RDFRQ
90F0 3E 03    474 HIGHP:   MVI  A,FXHIGHP     ;SELECT HIGH PASS (FAST PASS) FOR CLOCK AND SKEW
90F2 32 2770  475          STA  FLTFX
90F5 3E 02    476          MVI  A,FYHIGHP
90F7 32 1B70  477          STA  FLTKY
90FA CD 1B70  478 RDFRQ:   CALL INITAL        ;READ VARIABLES AND ARRAYS INCLUDING FLAGS
90FD CD 2E43  479          CALL BLANK         ;BLANK THE OLD DISPLAY
9100 06 04    480          MVI  B,4           ;B COUNTS THE NUMBER OF SWITCHES TESTED
9102 21 2B2B  481          LXI  H,CLOCKM      ;POINT HL TO CLOCK ADJUSTING FLAG
```

```
9105 3A 1370 462          LDA   TEMP          ;BRING BACK SWITCH READING
9108 07      463 RDFR1:   RLC                 ;TEST NEXT SWITCH BIT
9109 3E 00   464          MVI   A,00H
910B D2 1191 465          JNC   RDFR2         ;JUMP IF SWITCH IS OFF
910E 3E 01   466          MVI   A,01H
9110 AF      467          XRA   A             ;CLEAR A SO WILL ONLY RESPOND TO PUSH OF ONE SWITCH
9111 23      468 RDFR2:   INX   H             ;SET UP FOR NEXT SWITCH BIT
9112 05      469          DCR   B
9113 C2 0B91 470          JNZ   RDFR1         ;CONTINUE UNTIL ALL 4 SWITCHES TESTED
             471 ;
9116 21 FF06 472 RDFR3.   LXI   H,06FFH       ;SET UP LOOP COUNT FOR 1 SEC DELAY (21505 CYCLES)
9119 2D      473 RDFR4:   DCR   L             ;AND LOOP UNTIL IT TIMES OUT
911A C2 1991 474          JNZ   RDFR4
911D 25      475          DCR   H
911E C2 ?    476          JNZ   RDFR4
             477 ;
9121 3A 1080 478          LDA   PPSW          ;SEE IF ALL SWITCHES ARE RELEASED
9124 4F      479          CMA
9125 E6 0F   480          ANI   0FH
9127 C8      481          RZ                  ;RETURN IF THEY ARE
9128 C3 1691 482          JMP   RDFR3         ;OTHERWISE DELAY AND TEST AGAIN
             483 ;
             484 ;
             485 ;
             486 ;*****************************************************
             487 ;
             488 ;        SERVICE A/D DATA
             489 ;
             490 ;*****************************************************
             491 ;
             492 ;
     912B    493 ATOD     EQU   $             ;OBTAIN LIVE A/D DATA
             494 ;
             495 ; THIS IS TO READ FROM DATA UNTIL A/D SYSTEM IS REBOOTED
             496 ;
912B 3A 2E2B 497          LDA   ATODFF
912E A7      498          ANA   A             ;IF THE FROM FLAG IS SET GO READ FROM FROM
912F C2 F791 499          JNZ   ATODF
9132 3A 3120 500          LDA   ATODIF        ;SEE IF THIS IS THE FIRST TIME ATOD HAS BEEN
9135 A7      501          ANA   A             ;  CALLED AFTER INITIALIZING
9136 C2 4AA1 502          JNZ   ATOD1         ;IF NZ IT'S BEEN CALLED BEFORE
9139 21 0010 503          LXI   H,1000H       ;OTHERWISE INITIALIZE THE FROM POINTERS
913C 22 2A2B 504          SHLD  FRMPTR
913F 21 F401 505          LXI   H,500         ;  AND COUNTER
9142 22 322B 506          SHLD  FSCNT
9145 3E 01   507          MVI   A,01H         ;AND SET THE INITIALIZATION FLAG
9147 32 312B 508          STA   ATODIF
             509 ;
             510 ;*****************************************************
             511 ;
             512 ;        INPUT A/D DATA
             513 ;
             514 ;*****************************************************
             515 ;
             516 ;
     914A    517 ATOD1    EQU   $             ;OBTAIN LIVE A/D DATA
             518 ;
             519 ;
             520 ;        READ DATA FROM CHANNEL 1:  DOWNTO 0 (0-5V)
```

```
                        ;
                        ;
914A 3E 10      544 ADATA:      MVI     A,10H           ;START A/D CONVERSION ON CHANNEL 0
914C D3 71      545             OUT     71H
914E 3E 15      546             MVI     A,15            ;WAIT 100 MICRO SECONDS
9150 3E 15      547             MVI     A,15H
9152 3D         548 DLY:        DCR     A
9153 C2 5291    549             JNZ     DLY
9156 3A 2870    550             LDA     FLTR0           ;SELECT X FILTER
9159 F6 08      551             ORI     08H             ;ENABLE A/D
915B D3 71      552             OUT     71H
915D E6 F7      553             ANI     0F7H            ;TURN ON CONVERSION
915F 00         554             NOP
9160 00         555             NOP
9161 D3 71      556             OUT     71H
9163 DB 73      557 A/DRDY:     IN      73H             ;A/D DATA READY?
9165 E6 20      558             ANI     20H
9167 C2 6191    559             JNZ     ATOD2
916A DB 72      560             IN      72H             ;YES GET LEAST SIGNIFICANT 8 BITS FOR LP X
916C 32 A5A6    561             STA     X+5             ;AND STORE IN LEAST SIG. BYTE OF X
916F DB 73      562             IN      73H
9171 E6 03      563             ANI     03H             ;MASK OUT ALL BUT LEAST SIG 2 BITS
9173 EE 02      564             XRI     02H             ;2s COMPLEMENT OF X
9175 FE 02      565             CPI     02H
9177 FA 8991    566             JM      PLUS5           ;IF BIT 1 SET MUST PROPAGATE SIGN
917A F6 FC      567             ORI     0FCH
917C 32 A4A5    568             STA     X+2
917F 3E FF      569             MVI     A,0FFH
9181 32 A1A6    570             STA     X
9184 32 A3A6    571             STA     X+1
9187 C3 9291    572             JMP     GETY
918A 32 A4A8    573 PLUS5:      STA     X+2
918D AF         574             XRA     A
918E 32 A2A8    575             STA     X
9191 32 A3A8    576             STA     X+1
9194 3A 2870    577 GETY:       LDA     FLTR1           ;SELECT Y FILTER
9197 F6 08      578             ORI     08H             ;TURN ON ENABLE
9199 D3 71      579             OUT     71H             ;SET MUX
919B E6 F7      580             ANI     0F7H            ;TURN ON CONVERSION
919D 00         581             NOP
919E 00         582             NOP
919F D3 71      583             OUT     71H
91A1 3E 00      584             MVI     A,00H           ;START A/D
91A3 D3 71      585             OUT     71H
91A5 DB 73      586 A/DRDY1:    IN      73H             ;DATA READY?
91A7 E6 20      587             ANI     20H
91A9 C2 A391    588             JNZ     A/DRDY
91AC DB 72      589             IN      72H             ;YES GET LEAST SIGNIFICANT 8 BITS IN A
91AE 32 A9A8    590             STA     Y+5             ;AND STORE IN LEAST SIG. BYTE OF Y
91B1 DB 73      591             IN      73H
91B3 E6 03      592             ANI     03H             ;MASK OUT ALL BUT LEAST SIG 2 BITS
91B5 EE 02      593             XRI     02H
91B7 FE 02      594             CPI     02H
91BA FA C4A1    595             JM      PLUS51          ;IF BIT 1 SET MUST PROPAGATE SIGN
91BD F6 FC      596             ORI     0FCH
91BF 32 A6A8    597             STA     Y+2
91C2 3E FF      598             MVI     A,0FFH
91C4 32 A8A8    599             STA     Y
91C7 32 AAA8    600             STA     Y+1
91CA C3 D491    601             JMP     DONE
91CD 32 A6A8    602 PLUS51:     STA     Y+2
```

```
 1CD AF       602          XRA    A
91CE 32 1AAB 603          STA    Y
91D1 32 AAAB 604          STA    Y+1
91D4 21 A2AB 605 ICONE:   LXI    H,X             ;CONVERT   X+Y TO FLOATING POINT
91D7 CD AB1F 606          CALL   FUSH4
91DA 3E 1C   607          MVI    A,APLTD
91DC 32 010E 608          STA    MA1MC
91DF 21 A2AB 609          LXI    H,X
91E2 CD C41F 610          CALL   FUF4
91E5 21 AAAE 611          LXI    H,Y
91E8 CD AB1F 612          CALL   FUSH4
91EB 3E 1C   613          MVI    A,APLTD
91ED 32 010E 614          STA    MA1MC
91F0 21 AAAE 615          LXI    H,Y
91F3 CD C41F 616          CALL   FUF4
91F6 C9      617          RET
             618 ;
             619 ;
             620 ;  READ DATA FROM THE DATA POOL
             621 ;
             622 ;
     91F7    623 ATOUF    EQU    $
91F7 2A 2A2E 624          LHLD   FPNTR           ;FETCH UP THE DATA POINTER
91FA AF      625          XRA    A               ;ZERO THE ACCUMULATOR
91FB 32 A2AE 626          STA    X
91FE 32 A3AB 627          STA    X+1             ;CLEAR OUT WHAT S NOT NECESSITIES
9201 32 AAAB 628          STA    Y               ;IN X AND Y
9204 32 ABAB 629          STA    Y+1
9207 7E      630          MOV    A,M             ;GET Y VALUE LOW BYTE
9208 32 1AAB 631          STA    Y+3             ;AND STORE IT
920B 23      632          INX    H
920C 7E      633          MOV    A,M             ;GET Y VALUE HIGH BYTE
920D E6 80   634          ANI    80H             ;CHECK SIGN
920F CA 1A21 635          JZ     PLUSY
9212 3E FF   636          MVI    A,0FFH          ;IF NEGATIVE, PROPAGATE SIGN FOR 32 BITS
9214 32 A0AB 637          STA    Y
9217 32 AAAB 638          STA    Y+1
921A 7E      639 PLUSY:   MOV    A,M             ;REMEMB HIGH BYTE
921B 23      640          INX    H
921C 32 ACAB 641          STA    Y+2             ;AND STORE IT
921F 7E      642          MOV    A,M
9220 32 A5AB 643          STA    X+3             ;GET X LOW BYTE
9223 23      644          INX    H
9224 7C      645          MOV    A,M
9225 E6 80   646          ANI    80H             ;CHECK SIGN
9227 CA 3292 647          JZ     PLUSX
922A 3E FF   648          MVI    A,0FFH          ;PROPAGATE IF NECESSARY
922C 32 A2A5 649          STA    X
922F 32 A3AB 650          STA    X+1
9232 7E      651 PLUSX:   MOV    A,M
9233 23      652          INX    H
9234 32 A4AB 653          STA    X+2
9237 22 2A2E 654          SHLD   FPNTR
             655 ;
923A 21 A2AB 656          LXI    H,X             ;CONVERT X AND Y TO FLOATING POINT
923D CD AB1F 657          CALL   FUSH4
9240 3E 1C   658          MVI    A,APLTD
9242 32 010E 659          STA    MA1MC
9245 21 A2AB 660          LXI    H,X
9248 CD C41F 661          CALL   FUF4
```

```
924F 21 FAA2 663          LXI   H,Y
9252 CD A01F 664          CALL  PUSH4
9255 3E 10   665          MVI   A,NPLUS1
9257 32 0106 666          STA   MAXMC
925A 21 AAA8 667          LXI   H,Y
925D CD C41F 668          CALL  POP4
9260 C9      669          RET
             670 ;
             671 ;
             672 ;*****************************************************************
             673 ;
             674 ;  INITIALIZE VARIABLES USED IN PROGRAM UPDATE, AND DISPLAY
             675 ;
             676 ;*****************************************************************
     9261    677 WARMIN  EQU   $
             678 ;  ZERO THE ENTIRE VARIABLE ARRAY IN RAM A000-AC00
9261 21 00A8 679          LXI   H,VARBUF   ;H-L POINTS TO START OF THE VARIABLE ARRAY
9264 11 0000 680          LXI   D,VARBUF   ;D-E POINTS TO 1 BEYOND THE END OF VARIABLE ARRAY
9267 CD 8E92 681          CALL  CLEAR
             682 ;
             683 ;  ARRAY IS NOW ZEROED, SET THE NON-ZERO VARIABLES
926A 21 0180 684          LXI   H,8001H    ;FIRST 2 BYTES OF M IS ARE 0180
926D 22 00AA 685          SHLD  OLDM
9270 22 04AA 686          SHLD  NEWM
9273 22 EEAA 687          SHLD  PREVM
9276 22 EEAA 688          SHLD  DFATIU
9279 22 E6AA 689          SHLD  SMZM
927C 21 7BF5 690          LXI   H,0F57BH         ;THIS SHOULD BE FFFFH
927F 22 01A6 691          SHLD  CCTIME           ;CCTIME = #CCUMMS/SMPLER  IF FOR1KRAM
9282 21 0000 692          LXI   H,0000H          ;SET EQUAL TO 3 IVO HERE
9285 22 04A6 693          SHLD  CCTIME+2
             694 ;
             695 ;  INITIALIZE RAM 2800-2BFF TO ZERO
9288 21 0028 696          LXI   H,2800H     ;HL POINTS TO START OF ARRAY
928B 11 002C 697          LXI   D,2C00H     ;DE POINTS TO 1 BEYOND THE END
928E CD 8E92 698          CALL  CLEAR
9291 C9      699          RET
             700 ;
             701 ;  CLEAR MEMORY SUBROUTINE: HL POINTS TO THE START OF THE ARRAY
             702 ;
             703 ;
9292 AF      704 CLEAR: XRA   A           ;CLEAR ACCUMULATOR
9293 77      705        MOV   M,A
9294 23      706        INX   H           ;POINT H-L TO NEXT ARRAY LOCATION
9295 7D      707        MOV   A,L         ;HL = DE WHEN FINISHED
9296 BB      708        CMP   E
9297 C2 8E92 709        JNZ   CLEAR
929A 7C      710        MOV   A,H
929B BA      711        CMP   D
929C C2 8E92 712        JNZ   CLEAR
929F C9      713        RET
             714 ;
             715        ORG   9400H - 0100H
             716 ;
             717 ;*****************************************************************
             718 ;
             719 ;       SUBROUTINE TO DISPLAY A FLOATING POINT NUMBER ON THE VDU DISPLAY
             720 ;
             721 ;*****************************************************************
```

```
                        ;
                        ;    CALLING SEQUENCE:
                        ;         THIS SUBROUTINE EXPECTS THE DEC REGISTER PAIR TO BE DISPLAYED
                        ;         AT THE NUMBER TO BE DISPLAYED.
                        ;
                        ;         USES ALL REGISTERS EXCEPT C.
                        ;
                        ;
92F3 06 FF              DISBCD:   MVI   B,0FFH        ;REGISTER B IS USED FOR PLUS/MINUS SIGN IN DISPLAY
92F5 62                 MOV   H,D
92F6 6B                 MOV   L,E
92F7 7E                 MOV   A,M             ;GET EXPONENT BYTE
92F8 E6 80              ANI   80H             ; IF NEGATIVE SET B TO DISPLAY A MINUS SIGN
92FA CA 0343            JZ    DISP1
92FD 7E                 MOV   A,M
92FE D6 80              SUI   80H
9300 77                 MOV   M,A
9301 06 0A              MVI   B,0AH
9303 CD AD1F            DISP1:    CALL  PUSH4
9306 3E 08              MVI   A,ALOG          ; TAKE BASE TEN LOG OF NUMBER
9308 32 0108            STA   MATHC
930B 21 0190            LXI   H,190           ; AND SUBTRACT TWO
930E CD 8B1F            CALL  FSUB1
9311 CD E2F3            CALL  SHUFFL          ; LEAVE INTEGER PART IN FLOATING ACCUM
9314 32 1E70            STA   DUT+5           ; AND THIS IS THE EXPONENT OF TEN WE WILL DISPLAY
9317 21 0890            LXI   H,TEN           ;NOW PUSH TEN ON THE STACK
931A CD AD1F                   CALL PUSH4
931D 3E 19              MVI   A,AXCHP         ;AND INTERCHANGE TOS AND NOS
931F 32 0105            STA   MATHC
9322 3E 08              MVI   A,FMPY
9324 32 0108            STA   MATHC           ;AND TAKE 10 TO THE INTEGER(NUMBER)
9327 62                 MOV   H,D
9328 6B                 MOV   L,E
9329 CD AD1F            CALL  PUSH4
932C 78                 MOV   A,B
932D FE 0A              CPI   0AH
932F C2 3693            JNZ   DISP3
9332 7E                 MOV   A,M
9333 C6 80              ADI   80H
9335 77                 MOV   M,A
9336 3E 19              DISP3:    MVI   A,AXCHP
9338 32 0108            STA   MATHC           ;XCHG TOS AND NOS
933B 3E 13              MVI   A,DIV
933D 32 0105            STA   MATHC           ;AND DIVIDE
9340 3E 1E              MVI   A,FIXI
9342 32 0105            STA   MATHC           ;FIX IT TO 32 BIT FIXED POINT
9345 3E 37              MVI   A,EXTOP
9347 32 0106            STA   MATHC           ;PLACE A COPY ONTO THE STACK
934A 21 1490            LXI   H,THOUS
934D CD AD1F            CALL  PUSH4
9350 3E 2F              MVI   A,ADDIV         ;DIVIDE BY 100
9352 32 0108            STA   MATHC
9355 CD F193            CALL  SWITCH          ;READ IT OUT AND PUSH IT BACK ON
9358 32 0F70            STA   OUT             ;LEAST SIGNIFICANT BYTE LEFT IN A
935B 21 1490            LXI   H,THOUS
935E CD AD1F            CALL  PUSH4
9361 3E 2E              MVI   A,MULMUL        ;MULTIPLY RESULT BY 100
9363 32 0108            STA   MATHC
9366 3E 2D              MVI   A,ADSUB         ;AND SUBTRACT
9368 32 0108            STA   MATHC
```

```
93CE 3E 37    .82           MVI   A,AFIOD       ;PUSH A OUT
93D0 32 C108  .83           STA   MATHC
9373 21 1090  .84           LXI   H,ITEN        ;DIVIDE BY TEN
9376 CD AD1F  .85           CALL  PUSH4
9376 3E 2F    .86           MVI   A,ADIV
9378 32 0108  .87           STA   MATHC
937E CD F193  .88           CALL  SWITCH        ;SUBTRACT 10 TIMES RESULT
937E 32 1070  .89           STA   OUT+1
9381 21 1090  .90           LXI   H,ITEN
9384 CD AD1F  .91           CALL  PUSH4
9387 3E 2E    .92           MVI   A,AMUL
9389 32 0108  .93           STA   MATHC
938C 3E 2D    .94           MVI   A,ASUB
938E 32 0108  .95           STA   MATHC
9391 CD F193  .96           CALL  SWITCH        ;REMAINDER IS THE UNITS
9394 32 1170  .97           STA   OUT+2
9397 CD C693  .98           CALL    BLANK
939A 3A 0F70  .99           LDA     OUT
939D 32 004A  800           STA     LED6
93A0 3A 1170  801           LDA     OUT+1
93A3 32 0048  802           STA     LED5
93A6 3A 1170  803           LDA     OUT+2
93A9 32 0046  804           STA     LED4
93AC 78       805           MOV     A,B           ;DISPLAY EITHER BLANK OR MINUS SIGN
93AD 32 004C  806           STA     LED7
93B0 06 FF    807           MVI     B,0FFH        ;FILL B REGISTER WITH A BLANK
93B2 3A 1270  808           LDA     OUT+3
93B5 FE 00    809           CPI     00H           ;SET CONDITION CODES
93B7 CA BE93  810           JP      DISP2         ;IF ZERO OR
93BA 2F       811           CMA                   ;ELSE TWO'S COMPLEMENT THE ACCUMULATOR
93BB 3C       812           INR     A
93BC 06 0A    813           MVI     B,0AH         ;AND LOAD A MINUS SIGN INTO REGISTER B
93BE 32 0040  814 DISP2:    STA     LED1          ;DISPLAY THE EXPONENT
93C1 78       815           MOV     A,B           ;AND DISPLAY ITS SIGN
93C2 32 0042  816           STA     LED2
93C5 C9       817           RET
              818 ;
              819 ;     SUBROUTINE TO BLANK THE BCD DISPLAY
              820 ;
93C6 3E 0F    821 BLANK:    MVI   A,0FH           ;CLEAR TO ALL ZEROS
93C8 32 0042  822           STA   LED2
93CB 32 0044  823           STA   LED3
93CE 32 0046  824           STA   LED4
93D1 32 0048  825           STA   LED5
93D4 32 004A  826           STA   LED6
93D7 32 004C  827           STA   LED7
93DA 32 004F  828           STA   LED8            ;CLEAR THE DISPLAY COMPLETELY
93DD AF       829           XRA   A
93DE 32 0040  830           STA   LED1            ;AND OUTPUT A ZERO IN THE RIGHTMOST DISPLAY
93E1 C9       831           RET
              832 ;
93E2 3E 1E    833 SHUFFL:   MVI   A,AFIXD         ;FIX THE TOP OF THE STACK
93E4 32 0108  834           STA   MATHC
93E7 CD F193  835           CALL  SWITCH          ;SWITCH IT IN AND OUT
93EA 3E 1C    836           MVI   A,AFLTD
93EC 32 0108  837           STA   MATHC           ;REFLOAT THE STACK
93EF 79       838           MOV   A,C             ;LEAVE LSD IN A
93F0 C9       839           RET
              840 ;
93F1 21 1370  841 SWITCH:   LXI   H,TEMP
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93F4 CD C41F 840            CALL FDF4           ;FOR THE ABSOLUTE TOS INTO HL
93F7 4F      841            MOV  C,A            ;SAVE THE LSB AS C
93F8 21 1370 842            LXI  H,TEMP         ;IF SW 11 READ UNTIL HL AR9511
93FB CD AD1F 843            CALL PUSH4
93FE 79      844            MOV  A,C
93FF C9      845            RET
             846 ;
             847          ORG   9400H
             848 ;
             849 ;
             850 ;*****************************************************
             851 ;
             852 ;        DISPLY SUBROUTINE TO DISPLAY THE ALIGNMENT MATRIX
             853 ;
             854 ;*****************************************************
             855 ;
             856 ;
    9401     857 ADISPL  EQU   $
9401 3A 1C2B 858            LDA   CLOCKA        ;DISPLAY ERROR IF CLOCK ALGORITHM IS IN USE
9404 FE 00   859            ORI   00H           ;SET THE FLAGS
9406 CA E094 860            JZ    L200          ;IF NOT CLOCK ALGORITHM GO TO L200
9409 11 3BA6 861            LXI   D,ERELG
940C CD F392 862            CALL  DISBUF
940F C9      863            RET
             864 ;
9410 3A 1C2B 865 L200:      LDA   CROSSA        ;DISPLAY CORRELATION SCORE IF CORRELATION ALGORITHM
9413 FE 00   866            ORI   00H           ;  IS IN USE
9415 CA 1C00 867            JZ    L300          ;IF (.NOT. CROSSATION) GO 300
9418 21 352A 868            LXI   H,R44         ;HL = 352A (R44)
941B E5      869            PUSH  H
941C CD AD1F 870            CALL  PUSH4
941F 3E 17   871            MVI   A,17H         ;17 FOR
9421 32 0105 872            STA   MATHC
9424 21 6CA6 873            LXI   H,RMAX        ;RMAX=R(1)
9427 CD C41F 874            CALL  FDF4
942A 21 70A6 875            LXI   H,RMIN        ;RMIN=R(I)
942D CD E41F 876            CALL  FUFA
9430 21 0090 877            LXI   H,90H
9433 CD AD1F 878            CALL  PUSH4
9436 3E 17   879            MVI   A,17H         ;17
9438 32 0105 880            STA   MATHC
943B 21 4FA6 881            LXI   H,JMAX        ;JMAX=1
943E CD C41F 882            CALL  FDF4
9441 21 4FA6 883            LXI   H,JMIN
9444 CD C41F 884            CALL  FDF4          ;JMIN=1
9447 01 0000 885            LXI   B,0000H
944A F1      886 L400:      POP   D             ;GET ## R(J)
944B E5      887            PUSH  H             ;PRESERVE POINTER VALUE
944C 21 6CA6 888            LXI   H,RMAX
944F CD 701F 889            CALL  FSUBD
9452 CD E71F 890            CALL  FSTAT
9455 E6 40   891            ANI   40H
9457 C2 1595 892            JNZ   L490          ;IF(RMAX .GE. R(J)) GO TO 490
945A E1      893            POP   H
945B E5      894            PUSH  H             ;HL = ## R(J)  & POINTER STILL ON STACK
945C CD AD1F 895            CALL  PUSH4
945F 21 6CA6 896            LXI   H,RMAX
9462 CD C41F 897            CALL  FDF4          ;RMAX = R(J)
9465 79      898            MOV   A,C           ;C IS RUNNING COUNT OF LOOPS
9466 32 0005 899            STA   MATHD
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9509 78          901          MOV    A,B
950A 32 0008     902          STA    MATHB
950D CD A71F     904          CALL   FLOATC        ;FLOAT B-C
9510 21 4AAB     905          LXI    H,JMAX       ;JMAX = J
9513 CD C41F     906          CALL   POP4
9516 11 70A8     907 L390:    LXI    D,KMIN
9519 E1          908          POP    H            ;H-L = A(J)
951A E5          909          PUSH   H
951B CD 701F     910          CALL   FSUB2
951E CD F71F     911          CALL   MSTAT
9521 E6 40       912          ANI    40H
9523 C2 4095     913          JNZ    L300         ;IF(KMIN .LT. A(J)) GO TO 300
9526 CD AD1F     914          CALL   PUSH4        ;H-L  STILL POINTS AT A(J)
9529 21 70A8     915          LXI    H,KMIN
952C CD C41F     916          CALL   POP4         ;ELSE KMIN = A(J)
952F 79          917          MOV    A,C
9530 32 0008     918          STA    MATHB
9533 78          919          MOV    A,B
9534 32 0008     920          STA    MATHB
9537 CD A71F     921          CALL   FLOATC
953A 21 4AA8     922          LXI    H,JMIN       ;JMIN = J
953D CD C41F     923          CALL   POP4
9540 E1          924 L3900:   POP    H            ;POP POINTER VALUE OFF STACK
9541 23          925          INX    H
9542 23          926          INX    H
9543 23          927          INX    H
9544 23          928          INX    H            ;INCREMENT TO NEXT ARRAY LOCATION
9545 E5          929          PUSH   H            ;AND REPUSH
9546 03          930          INX    B            ;INCREMENT COUNTER
9547 79          931          MOV    A,C
9548 FE 31       932          CPI    49D          ;DONE LOOPING?
954A C2 8494     933          JNZ    DLOOP
954D E1          934          POP    H            ;DO IT NOW!!!!
954E 21 6CA8     935          LXI    H,KMAX
9551 CD AD1F     936          CALL   PUSH4
9554 21 74A8     937          LXI    H,KPEAK
9557 CD C41F     938          CALL   POP4         ;KPEAK = KMAX
955A 21 4BA8     939          LXI    H,JMAX
955D CD AD1F     940          CALL   PUSH4
9560 21 53A8     941          LXI    H,JPEAK
9563 CD C41F     942          CALL   POP4         ;JPEAK = JMAX
9566 21 70A8     943          LXI    H,KMIN
9567 CD AD1F     944          CALL   PUSH4
956C 3E 15       945          MVI    A,ALHSF
956E 32 0108     946          STA    MATHC        ;-KMIN ON STACK
9571 21 6CA8     947          LXI    H,KMAX
9574 CD 7B1F     948          CALL   FSUB1
9577 CD F71F     949          CALL   MSTAT
957A E6 40       950          ANI    40H
957C C2 9795     951          JNZ    L301         ;IF (KMAX .GE. -KMIN) GO TO 301
957F 21 70A8     952          LXI    H,KMIN
9582 CD AD1F     953          CALL   PUSH4
9585 21 74A8     954          LXI    H,KPEAK
9588 CD C41F     955          CALL   POP4         ;KPEAK = KMIN
958B 21 4FA8     956          LXI    H,JMIN
958E CD AD1F     957          CALL   PUSH4
9591 21 53A8     958          LXI    H,JPEAK
9594 CD C41F     959          CALL   POP4         ;JPEAK = JMIN
9597 11 74A8     960 L301:    LXI    D,KPEAK
959A 21 B6A8     961          LXI    H,XX
```

```
                        CALL    FDIV2
                        LXI     H,YEAR
                        CALL    FDF4            ;DISPLAY = YEAR/XX
                        LXI     D,YEAR
                        LXI     H,DISYEAR
                        CALL    FDIV2
                        LXI     H,CLTIME
                        CALL    FDAV1
                        LXI     H,CURSLP
                        CALL    FDF4            ;CURSLP = (YEAR/XX+CLTIME
                        LXI     D,CURSLP        ;DISPLAY THE CORRELATION SLOPE
                        CALL    DISRLD
                        RET
                ;
                ;  SLOPE ALGORITHM
                ;
95C2 3A 2828    L305:   LDA     SLOPEA          ;DISPLAY THE SLOPE IF THE SLOPE ALGORITHM IS IN USE
95C5 F6 00              ORI     00H             ;SET THE FLAGS
95C7 CA E095            JZ      L307            ;IF NOT SLOPE ALGORITHM GO TO 307
95CA 11 82AB            LXI     D,SLOPE
95CD 21 8638            LXI     H,XX
95D0 CD 8F1F            CALL    FDIV2
95D3 21 9EAB            LXI     H,WKSLOP
95D6 CD C41F            CALL    FDF4            ;WKSLOP SLOPE/XX
95D9 11 9EAB            LXI     D,WKSLOP        ;DISPLAY THE SLOPE
95DC CD F392            CALL    DISRLD
95DF C9                 RET
                ;
                ;  SKEW MEASUREMENT
                ;
95E0 3A 2928    L307:   LDA     SKEWA           ;DISPLAY SKEW IF SKEW ALGORITHM IS IN USE
95E3 F6 00              ORI     00H
95E5 CA 7796            JZ      L309            ;IF NOT SKEW ALGORITHM GO THE 308
                ;
95E8 21 26AB            LXI     H,DXDX          ;GEO=(DXDX*DYDY)**.5
95EB 11 2EAB            LXI     D,DYDY
95EE CD E11F            CALL    FMULT
95F1 3E 01              MVI     A,ASORT
95F3 32 0108            STA     MATHC
95F6 21 42AB            LXI     H,GEO
95F9 CD C41F            CALL    FDF4
                ;
95FC 11 42AB            LXI     D,GEO           ;F1=GEO/XX
95FF 21 16AB            LXI     H,XX
9602 CD 8F1F            CALL    FDIV2
9605 21 0AAB            LXI     H,F1
9608 CD C41F            CALL    FDF4
                ;
960B 11 22AB            LXI     D,YDY           ;F15=YDY/XX
960E 21 16AB            LXI     H,XX
9611 CD 8F1F            CALL    FDIV2
9614 21 2DAB            LXI     H,F15
9617 CD C41F            CALL    FDF4
                ;
961A 11 16AB            LXI     D,DUMMY         ;F15=DUMMY/XX
961D 21 16AB            LXI     H,XX
9620 CD 8F1F            CALL    FDIV2
9623 21 2DAB            LXI     H,F15
9626 CD C41F            CALL    FDF4
                ;
```

```
9629 11 E1AB 031          LXI   D,P12          ;P12 = P12 - P16*P12
962C 21 00AB 032          LXI   H,P16
962F CD E11F 033          CALL  FMUL2
9632 21 E0AB 034          LXI   H,P12
9635 CD C41F 035          CALL  FUP4
                  036 ;
9638 21 00AB 037          LXI   H,P16          ;LM2=P16-(P16*P16)
963B CD A01F 038          CALL  PUSH4
963E 21 00AB 039          LXI   H,P16
9641 11 E0AB 040          LXI   D,P16
9644 CD E11F 041          CALL  FMUL2
9647 CD 781F 042          CALL  FSUB
964A 21 05AB 043          LXI   H,LM2
964D CD C41F 044          CALL  FUP4
                  045 ;
9650 11 E1AB 046          LXI   D,P15          ;SKEW = (P15-P12*P12) - 2*P16*LM2
9653 21 E0AB 047          LXI   H,P12*P12
9656 CD 701F 048          CALL  FSUB2
9659 11 0490 049          LXI   D,TWO
965C 21 00AB 050          LXI   H,P16
965F CD E11F 051          CALL  FMUL2
9662 21 05AB 052          LXI   H,LM2
9665 CD E51F 053          CALL  FMUL1
9668 CD 781F 054          CALL  FSUB
966B 21 E1AB 055          LXI   H,SKEW
966E CD C41F 056          CALL  FUP4
                  057 ;
9671 11 E1AB 058          LXI   D,SKEW         ;DISPAY SKEW
9674 CD F392 059          CALL  DISBCD
9677 C9      060 L3088:   RET
                  061 ;
                  062 ;
                  063       END
```

```
M       0057    MMODS   0016    ABLAM   0005    AMTAN   0007    ALMSD   0031
ALMSE   0015    ACMSS   0074    ALOS    0006    ADVDU   002C    ANITV   002F
ADISPL  Y4A1    ADMUL   002E    ADMOD   0036    ADSUB   002D    ALXP    0008
APADD   0010    AFDIV   0013    AFIXD   001E    AFIXS   001F    AFLTD   0016
AFLTS   0018    AFMUL   0012    AFSUB   0011    AJFITA  Y25B    ALN     0000
ALOG    0008    ANOP    0000    APOFD   0038    APOFF   0016    APOFS   0078
APTOD   0037    APTOF   0017    APTOS   0077    APUSH   0018    AREM    0006
ASCADD  0006    ASCMEM  Y0E0    ASDIV   0008    ASIN    0002    ASMUL   0C6E
ASMOD   0076    ASQRT   0001    ASSUB   0008    ASTAN1  Y039    ATAN    0004
ATOD    Y128    ATODD1  Y14A    ATODL   Y161    ATOS    Y1A5    ATODIF  2B51
ATODM   Y1F7    ATODMF  2B2E    AXCHD   0039    AXCHF   0019    AXCHS   0079
B       0000    BEGIN   1B43    BLANK   9306    BUFFER  A600    C       0001
CLDWNS  Y016    CLTIME  A802    CLEAR   Y28E    CLFVEC  7006    CLOCKA  2B16
CM2     AE06    CORSLP  AE0A    CR      0009    CFOSSA  2B27    CSUM    7001
D       0002    DATA    1000    DC2M    AAD5    DCEXPT  A20E    DDX     Ae12
DDXDY   AB16    DDXDYM  AYAe    DDYDY1  AAA2    DDY     AB1A    DISBCD  Y2F3
DISP1   Y393    DISP2   Y3AE    DISPDM  AAA0    DISPS   Y336    DISPLY  7024
DLOOP   Y4EA    DOATD   Y14A    DOJ     3B25    DONE    9104    DSEXPT  AB1E
DX      AB22    DXDX    AB26    DXDXM   AYA0    DYDX1   AAA6    DXJYM   AYAE
DXDY1   AAAA    DY      AB2A    DYDY    Ab2E    DYDYM   Y9B2    DYDY1   AAAE
E       0004    EARD    1e25    EARSUB  1e39    FALEF1  A4B2    FARD    1F6A
FADD1   1F67    FADD2   1F62    FDIV    1F97    FDIX1   1F94    FDIV2   1FB4
FLOAT   1F9D    FLLATE  1FA7    FLTRX   7027    FLTRY   7022    FMAX    Ae3D
FMUL    1FB4    FMUL1   1FBe    FMUL2   1FB1    FPLITE  3900    FPSW    A000
FREG    Ae3e    FREGDM  AA0E    FREXPT  Ae3A    FREXT   Ae3F    FRTERM  AA0e
FSUB    1F7I    FSUB1   1F7E    FSUB2   1F70    GED     AA42    GETT    Y1Y2
GOBAIL  2024    GRATIO  A4E2    H       0004    HIGHF   Y0F0    IHUNP   Y014
INDEXO  2B2F    INDEX1  AB6e    INDEX2  Ab46    INITAL  7018    ISAMPL  Ab1A
ITER    Y010    JREM    1A02    JMAX    Ab4A    JMIN    Ab4F    JPEAK   Ac53
L       0005    L200    Y4B0    L290    Y516    L300    Y540    L301    Y597
L305    Y5L2    L307    Y5E0    L308    9677    LEN1    6000    LEN2    4200
LEN3    4400    LEN4    4600    LEN5    4800    LEN6    4A00    LEN7    4C00
LEN9    4F00    LF      000A    M       0006    MATHC   0801    MATHM   0800
MINS10  AB57    MSKE    Ab58    MSTAT   1FF7    MXHCE   9019    MXHSE   901D
MXPRE   Y0J1    MXSKE   Y0J5    NALEFT  A9B6    ONE     9000    ONEM    900C
OUT     7004    P11P12  Ab5C    P12     Abe9    P13     AB64    P16     Ab6B
PLUS5   Y1B9    PLUS51  Y1LA    PLUSX   9232    PLUSY   Y21A    POP4    1FD4
PRAMTR  2B2A    PROUES  701E    PSLMT   2B33    PSW     0006    PUSH4   1FAD
R       2A54    RDFR1   Y106    RDFR2   9111    RDFR3   9116    RDFR4   9119
RDFR5   90FA    RDFRM1  9001    RESTAR  1RDL    RJIABS  7015    RMAX    AB6C
RKIN    Ab70    RNEJ    AYDA    RNEW    AbDE    RPEAK   Ab74    RSTCNT  0000
RTERMS  Ay5A    RX      2AFC    RX50    2B20    RXTMTR  Ab7B    RY      2BD4
RYTRIR  Ae7A    SCALE1  Ab7C    SCALE2  Ab80    SCR2    909L    SCR3    90C3
SCR5    90FF    SCREEN  701R    SCRMTR  2B2C    SCRAT   7000    SHUFFL  93E2
SIDE    8901    SIDE2   8001    SKIP    AAE6    SNEW    Ab84    SNEWA   2B29
SPEXPT  Ab5B    SPOTE   Ab8C    SLOPEA  2B2E    SLPNEW  Ab8C    SLPNEW  Ay8E
SRATCH  90LY    SS      0006    STACK   7100    STAPT   7015    STARTI  905A
STATUS  9060    SWITCH  Y3F1    TMDES   AYDC    TEMP    7013    TEMP0   Ae70
TEP     9005    TEST    9060    TEST3   9087    TEST4   9078    TMETA   Ae52
TMPTWL  Ab75    TMETWL  902D    TMETA1  AYE2    TMETA2  AABE    TWO     9004
UNIT    9031    UPCHG   2B32    UPKOPE  AYDA    UPKOPS  AC0E    UPDATE  9021
UPTIME  9029    VELOCC  Ab77    VALDXY  Ae9D    VBOPE   A0EA    VBOPS   Ae3C
WHSLOT  Ae9E    X       Ab0A    XDL     Ab4e    XLCMET  AA02    XDCMEW  AY06
XHIGHM  0005    XLOWM   0001    XS      Ab0A    XX      Ab66    XXN     AYL4
XY      AA0e    Y       Ab1A    YDL     Ab8E    YDCMET  AA0A    YDCMEW  AYLE
YDX     Ab02    YDYN    AYD2    YDX1    AA0E    YHIGHM  0002    YLOWM   0000
YS      Ab0e    YY      Ab0C    YYN     AYD6    YY1     AAD2    ZLSW    Ac0A
ZSD     Ab0e
ZSDMIN  Y035
```

```
>805      0000 -
mS
xC

                1 ;  MONITOR
                2 ;  11/28/79
                3 ;  CHANGES
                4 ;  11/23  NUMBER OF AND DISPLAY ETC MOVED TO MONI
                5 ;  11/11/79 -- RECOVERED 11/09/79 FROM INT FILE. SOURCE SHOULD BE CHECKED!!
                6 ;  DISPLAY MODED
                7 ;  MOR DISPLAY CONSTANTS AND VSII ROUTINES ADDED
                8 ;
                9 ;
               10 ;
               11 ;*************************************************************
               12 ;*
               13 ;  MISC LOCAL EQUATES TO ASSEMBLE THIS FROM
               14 ;
               15 ;*************************************************************
               16 ;
FFFF           17 DLY     EQU     -1
000D           18 CR      EQU     0DH             ; CARRIAGE RETURN
000A           19 LF      EQU     0AH             ; LINE FEED
0000           20 XXXXXX  EQU     0               ; DUMMY ARGUMENT
00EF           21 RST33   EQU     0EFH            ; RST 3 INSTRUCTION
7100           22 STACK   EQU     7100H           ; STACK TOP
7000           23 SCRAT   EQU     7000H           ; SCRATCHPAD
7001           24 CSUM    EQU     7001H           ; CHECKSUM
7013           25 TEMP    EQU     7013H           ; TEMPORARY STORAGE
7029           26 BLKCNT  EQU     7029H
0801           27 MATHC   EQU     0801H
0800           28 MATHD   EQU     0800H
001D           29 AFLTS   EQU     1DH
0013           30 AFDIV   EQU     13H
0012           31 AFMUL   EQU     12H
0010           32 AFADD   EQU     10H
0011           33 AFSUB   EQU     11H
4000           34 LED1    EQU     4000H
4F00           35 LED8    EQU     4F00H
93CE           36 BLANK   EQU     93CEH       ;BLANK THE DISPLAY SUBROUTINE
               37 ;
               38 ;*************************************************************
               39 ;
               40 ;  8251 EQUATES
               41 ;
               42 ;*************************************************************
               43 ;
00C0           44 S1C     EQU     0C0H            ; SERIAL WITH MODEM PORT
00C1           45 S1CC    EQU     0C1H            ; CONTROL PORT
00C0           46 S1D2    EQU     0C0H            ; SERIAL PORT #2
00C1           47 S1CC2   EQU     0C1H            ; CONTROL PORT #2
               48 ;
               49 ; MODE -- 2 STOP, NO PARITY, 16X CLOCK
               50 ;
00CE           51 MODE    EQU     11001110B       ; INITIAL MODE AFTER RESET COMMAND
               52 ;
               53 ;  STATUS BITS (AS READ AT S1CC)
               54 ;
0002           55 SRRDY EQU   00000010B           ; RECIEVER READY WITH CHARACTER
0001           56 STRDY EQU   00000001B           ; SERIAL I/O COMMAND ACCEPTS
```

```
                        57 ;
                        58 ; PIN COMMANDS
                        59 ;
     0001               60 STEN   EQU   00000001B           ; TRANSMITTER ENABLE
     0002               61 SDTR   EQU   00000010B           ; SET DTR LINE
     0004               62 SREN   EQU   00000100B           ; SET RECEIVER ENABLE
     0007               63 SRUN   EQU   STEN+STEN+SDTR      ; FOR COMMUNICATION
                        64 ;
                        65 ;*****************************************************************
                        66 ;
                        67 ;           TIMER EQUATES
                        68 ;
                        69 ;*****************************************************************
     0000               70 SC0      EQU     00000000B           ; COUNTER NUMBER 0
     0040               71 SC1      EQU     01000000B           ; COUNTER NUMBER 1
     0030               72 RL1      EQU     00110000B           ; READ/LOAD LEAST/MOST BYTE
     0006               73 M3       EQU     00000110B           ; SQUARE WAVE GENERATOR
     0000               74 BCD      EQU     00000000B           ; BINARY COUNTERS 16 BITS
     0036               75 TMODE1   EQU     SC0+RL1+M3+BCD      ; TIMER 1 MODE
     0076               76 TMODE2   EQU     SC1+RL1+M3+BCD      ; TIMER 2 MODE
                        77 ;
                        78          ORG   1800H
                        79 ;
1800 3E 0E              80 MINIT: MVI   A,MODE              ; SET UP 8251
1802 32 0168            81        STA   S1CC               ; REF /IT
1805 32 0160            82        STA   S1CC2              ; FOR 75-2400
1808 3E 07              83        MVI   A,SRUN
180A 32 0168            84        STA   S1CC
180D 32 0160            85        STA   S1CC2
1810 C9                 86        RET
                        87 ;
1811 0D                 88 CLRS:  DB    CR,LF,'8085A'
1812 0A
1813 38303835
1817 41
1818 20                 89 VERNO: DB    ' '
     0008               90 LVER   EQU   VERNO-CLRS+1
                        91 ;
1819 0D                 92 ERRM:  DB    CR,LF,'RST
181A 0A
181B 52535420
181F 28092045           93 ERRE:  DB    '(E) EX'
1823 58
1824 20                 94 ERRE2: DB    ' '
                        95 ;
1825 21 1918            96 ERRD:  LXI   H,ERRM
1828 16 07              97        MVI   D,LVER+2
182A CD 3918            98        CALL  ERSOB
182D 4B                 99        MOV   C,E
182E CD 1218           100        CALL  CO
1831 16 05             101        MVI   D,ERRE2-ERRM
1833 CD 3918           102        CALL  ERSOB
1836 C3 0C18           103        JMP   MSTART
1839 4E                104 ERSOB: MOV   C,M
183A 23                105        INX   H
183B CD 1218           106        CALL  CO
183E 15                107        DCR   D
183F C2 3918           108        JNZ   ERSOB
1842 C9                109        RET
                       110 ;
```

```
                        111 ;
                        112 ; MONRAM ENTRY POINT.
                        113 ;
                        114 ; COMPUTE THE TOP OF RAM MEMORY AVAILABLE ON THIS SYSTEM
                        115 ; AND RELOCATE THE USER REGISTER SAVE AREA, EXIT TEMPLATE, AND
                        116 ; MONITOR STACK AT THE TOP OF RAM.
                        117 ;
1843 21 0371            118 BEGIN: LXI     H,STACK          ; MOVE EXIT TEMPLATE TO TOP OF
1846 06 12              119        MVI     B,REND-EXIT
1848 11 7F1C            120        LXI     D,ENDX
184B 1B                 121 BEG1:  DCX     D
184C 1A                 122        LDAX    D
184D 2B                 123        DCX     H
184E 77                 124        MOV     M,A
184F 05                 125        DCR     B
1850 C2 4B18            126        JNZ     BEG1
1853 F9                 127        SPHL
1854 CD 0018            128        CALL    HINIT            # INITIALIZE HARDWARE
1857 CD 7D1C            129        CALL    TIMER            # INITIALIZE 8155 TIMER FOR BAUD
185A 21 CE70            130        LXI     H,STACK-(TEMPLT-EXIT)-32  # CLEAR OF USER REG SAVE AREA
185D E5                 131        PUSH    H                # SET TO INITIAL VALUES
185E 21 0000            132        LXI     H,0
1861 E5                 133        PUSH    H
1862 E5                 134        PUSH    H
1863 E5                 135        PUSH    H                # PUSH REGISTERS ON STACK
                        136 ;
                        137 ; TYPE SIGN-ON
                        138 ;
1864 21 1118            139        LXI     H,VERS           # ADDRESS OF MESSAGE
1867 16 0B              140        MVI     D,LEVER          # LENGTH OF MESSAGE
1869 CD 3918            141        CALL    ERSUB
                        142 ;
                        143 ; MAIN COMMAND LOOP.
                        144 ;
                        145 ; THIS LOOP IS THE STARTING POINT OF ALL COMMAND SEQUENCES.
                        146 ; IN THIS CODE INTERRUPTS ARE ENABLED, ALL I/O DEVICES
                        147 ; ARE INITIALIZED, A CARRIAGE RETURN AND LINE FEED ARE TYPED,
                        148 ; ALONG WITH THE PROMPT CHARACTER '.'.  WHEN A CHARACTER IS
                        149 ; ENTERED FROM THE CONSOLE KEYBOARD, IT IS CHECKED FOR VALIDITY.
                        150 ; THEN A BRANCH TO THE PROPER PROCESSING ROUTINE IS COMPUTED.
                        151 ;
186C FB                 152 MSTART: EI                       # RE-ENABLE INTERRUPTS
186D CD 6418            153        CALL    CRLF             # TYPE CR-LF-'.'
1870 0E 2E              154        MVI     C,'.'
1872 CD 1218            155        CALL    CO               # OUTPUT A PERIOD
1875 CD 5C1C            156        CALL    CI               # GET A CHARACTER
1878 D6 41              157        SUI     'A               # TEST FOR A-F
187A FA 6C18            158        JM      MSTART           # IF A, ERROR
187D FE 18              159        CPI     'F'-'A'+1
187F F2 6418            160        JP      LER              # OR F, ERROR
1882 FE 09              161        CPI     'J'-'A'          #RELOAD FOR EXTENSION LOOKUP-- TEST FOR J COMM.
1884 D2 8B18            162        JNC     NOTJ
1887 01 6C18            163        LXI     B,MSTART         #JUMP "RETURN ADDRESS"
188A C5                 164        PUSH    B                #IF CALLED AS SUBROUTINE, JUMP RETURNS
                        165                                 #IF JUMPED TO, JUMP RETURNS TO START
1888 87                 166 NOTJ:  ADD     A                # *2
188C 21 9C18            167        LXI     H,TABL           # ADDRESS TO TABLE
188F D5                 168        PUSH    D                # SAVE DE
1890 5F                 169        MOV     E,A              # SAVE LSB'S
1891 16 00              170        MVI     D,0              # ZERO UPPER BITS
```

```
1893 19          171         DAD     D               # ADD TO TABLE BASE
1894 D1          172         POP     D               # RESTORE DE
1895 7E          173         MOV     A,M             # GET LSB OF ADDRESS
1896 23          174         INX     H               # POINT TO NEXT ADDRESS
1897 66          175         MOV     H,M             # GET MSB OF ADDRESS
1898 6F          176         MOV     L,A             # LSB TO L
1899 0E 02       177         MVI     C,2             # C IS SET UP FOR 2 PARAMETER COMMANDS
189B E9          178         PCHL                    # BRANCH TO ROUTINE
                 179 #
                 180 # COMMAND BRANCH TABLE.
                 181 #
                 182 # THIS TABLE CONTAINS THE ADDRESSES OF THE ENTRY POINTS OF
                 183 # ALL THE COMMAND PROCESSING ROUTINES.  NOTE THAT AN ENTRY TO 'LER'
                 184 # IS AN ERROR CONDITION, I.E., NO COMMAND CORRESPONDING TO THAT
                 185 # CHARACTER EXISTS.
                 186 #
189C 041B         187 TBL:    DW      LER             # A -
189E 041B         188         DW      LER             # B -
18A0 041B         189         DW      LER             # C -
18A2 CC1B         190         DW      DISP            # D - DISPLAY RAM MEMORY
18A4 041B         191         DW      LER             # E -
18A6 EB1B         192         DW      FILL            # F - FILL MEMORY
18A8 FE1B         193         DW      GOTO            # G - GO TO MEMORY ADDRESS
18AA 041B         194         DW      LER             # H -
18AC 481Y         195         DW      INHEX           # I - HUNK LINE LOADER INO BRAM
18AE 171A         196         DW      JHEX            # J - JUNK LINE LOADER INO BRAM
18B0 041B         197         DW      LER             # K -
18B2 041B         198         DW      LER             # L -
18B4 2B1A         199         DW      MOVE            # M - MOVE MEMORY
18B6 041B         200         DW      LER             # N -
18B8 041B         201         DW      LER             # O -
18BA 041B         202         DW      LER             # P -
18BC 041B         203         DW      LER             # Q -
18BE 041B         204         DW      LER             # R -
18C0 3E1A         205         DW      SUBS            # S - SUBSTITUTE MEMORY
18C2 041B         206         DW      LER             # T -
18C4 041B         207         DW      LER             # U -
18C6 041B         208         DW      LER             # V -
18C8 041B         209         DW      LER             # W -
18CA 6C1A         210         DW      XA              # X - EXAMINE AND MODIFY REGISTERS
                 211 #
                 212 # DISPLAY MEMORY IN HEX ON CONSOLE DEVICE.
                 213 #
                 214 # THIS ROUTINE EXPECTS TWO HEXADECIMAL PARAMETERS SPECIFYING
                 215 # THE BOUNDS OF A MEMORY AREA TO BE DISPLAYED ON THE
                 216 # CONSOLE DEVICE.  THE MEMORY AREA IS DISPLAYED 16 BYTES
                 217 # PER LINE, WITH THE MEMORY ADDRESS OF THE FIRST BYTE
                 218 # PRINTED FOR REFERENCE.  ALL LINES ARE BLOCKED INTO INTEGRAL
                 219 # MULTIPLES OF 16 FOR CLARITY, SO THAT THE FIRST AND LAST
                 220 # LINES MAY BE LESS THAN 16 BYTES IN ORDER TO SYNCHRONIZE THE
                 221 # DISPLAY.
                 222 #
18CC CD 731B     223 DISP:   CALL    EXPR            # GET TWO ADDRESSES
18CF D1          224         POP     D               # GET HIGH ADDRESS
18D0 E1          225         POP     H               # GET LOW ADDRESS
18D1 CD 641B     226 D10:    CALL    CRLF
18D4 CD B71B     227         CALL    LAUN            # PRINT MEMORY ADDRESS
18D7 CD 101B     228 D11:    CALL    BLP             # PRINT SPACE
18DA 7E          229         MOV     A,M
18DB CD BF1B     230         CALL    LBYTE           # PRINT DATA
```

```
18DE CD A71A 231         CALL    HILO            ; TEST FOR COMPLETION
18E1 DA 6C18 232         JC      MSTART
18E4 7D      233         MOV     A,L
18E5 E6 0F   234         ANI     0FH             ; PRINT CHARACTERS IN MULTIPLE OF 16
18E7 C2 D718 235         JNZ     DI1
18EA C3 D118 236         JMP     DIO
                         237 ;
                         238 ;
                         239 ; FILL RAM MEMORY BLOCK WITH CONSTANT.
                         240 ;
                         241 ; THIS ROUTINE EXPECTS THREE HEXADECIMAL PARAMETERS. THE
                         242 ; FIRST AND SECOND (16 BITS) ARE INTERPRETED AS THE BOUNDS
                         243 ; OF A MEMORY AREA TO BE INITIALIZED TO A CONSTANT VALUE.
                         244 ; THE THIRD PARAMETER (8 BITS) IS THAT VALUE.
                         245 ;
18ED 0C      246 FILL:   INR     C               ; GET 3 PARAMETERS
18EE CD 731A 247         CALL    EXPR
18F1 C1      248         POP     B               ; GET DATA IN C
18F2 D1      249         POP     D               ; GET HIGH ADDRESS
18F3 E1      250         POP     H               ; GET LOW ADDRESS
18F4 71      251 FIO:    MOV     M,C             ; STORE CONSTANT IN MEMORY
18F5 CD A71A 252         CALL    HILO            ; TEST FOR COMPLETION
18F8 D2 F418 253         JNC     FIO             ; CONTINUE LOOPING
18FB C3 6C18 254         JMP     MSTART
                         255 ;
                         256 ; GO TO <ADDRESS>, OPTIONALLY SET BREAKPOINTS.
                         257 ;
                         258 ; THE G COMMAND IS USED FOR TRANSFERRING CONTROL FROM THE
                         259 ; MONITOR TO A USER PROGRAM.  IT HAS SEVERAL MODES OF
                         260 ; OPERATION.
                         261 ;
                         262 ; IF ONE HEXADECIMAL PARAMETER IS ENTERED, IT IS INTERPRETED
                         263 ; AS THE ENTRY POINT OF THE USER PROGRAM AND A TRANSFER TO
                         264 ; THAT LOCATION IS EXECUTED.
                         265 ;
                         266 ; IF ADDITIONAL (UP TO 2) PARAMETERS ARE ENTERED, THESE ARE
                         267 ; CONSIDERED 'BREAKPOINTS', I.E., LOCATIONS WHERE
                         268 ; CONTROL IS TO BE RETURNED TO THE MONITOR, IF THEY ARE
                         269 ; ENCOUNTERED.
                         270 ;
                         271 ; IF THE FIRST PARAMETER IS NOT ENTERED, THE STORED VALUE
                         272 ; OF THE USER'S PROGRAM COUNTER (REGISTER PC) IS USED AS
                         273 ; THE USER PROGRAM ENTRY POINT.
                         274 ;
18FE CD E11A 275 GOTO:   CALL    PCHK            ; GET A CHARACTER
1901 DA 4019 276         JC      GO3             ; CR ENTERED, EXIT
1904 CA 1819 277         JZ      GO0             ; DON'T MODIFY PC
1907 CD 9F1A 278         CALL    EXP             ; GET NEW PC VALUE
190A D1      279         POP     D
190B 21 1500 280         LXI     H,PSAVE
190E 39      281         DAD     SP
190F 72      282         MOV     M,D             ; STORE MODIFIED PC IN RAM
1910 2B      283         DCX     H
1911 73      284         MOV     M,E
1912 7B      285         MOV     A,B             ; RETRIEVE DELIMITER CHARACTER
1913 FE 0D   286         CPI     CR
1915 CA 4019 287         JZ      GO3             ; NO TRAPS TO BE SET
1918 16 02   288 GO0:    MVI     D,2             ; SET MAXIMUM OF TWO TRAPS
191A 21 1400 289         LXI     H,TFLAG
191D 39      290         DAD     SP
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191E E5        291 GU1:  PUSH    H               ; SAVE ADDRESS OF TRAP AREA
191F 0E 01     292       MVI     C,1
1921 CD 731B   293       CALL    E/PK            ; GET A TRAP ADDRESS
1924 58        294       MOV     E,B             ; SAVE DELIMITER CHARACTER
1925 C1        295       POP     B               ; GET ADDRESS IN BC
1926 E1        296       POP     H
1927 78        297       MOV     A,B
1928 B1        298       ORA     C
1929 CA 3819   299       JZ      GU2             ; DON'T ALLOW A TRAP AT 0
192C 71        300       MOV     M,C             ; PUT TRAP ADDRESS AWAY
192D 23        301       INX     H
192E 70        302       MOV     M,B
192F 23        303       INX     H
1930 0A        304       LDAX    B               ; FETCH OPCODE
1931 77        305       MOV     M,A             ; PUT IN TRAP AREA
1932 23        306       INX     H
1933 3E CF     307       MVI     A,RST1          ; RESTART 1 INSTRUCTION
1935 02        308       STAX    B               ; SET TRAP IN MEMORY
1936 7B        309 GU2:  MOV     A,E             ; TEST DELIMITER CHARACTER
1937 FE 0D     310       CPI     CR
1939 CA 4019   311       JZ      GU3             ; ALL DONE
193C 15        312       DCR     D
193D C2 1E19   313       JNZ     GU1             ; GO GET NEXT TRAP
1940 CD 041B   314 GU3:  CALL    CRLF
1943 21 0800   315       LXI     H,8
1946 39        316       DAD     SP
1947 E9        317       PCHL                    ; TAKE THE BRANCH
               318 ;
               319 ;   THIS EXPECTS AN 'I' COMMAND FROM THE MONITOR FIT
               320 ;   AND THE TURNS THE SYSTEM OVER TO THE SECOND UART.
               321 ;   THE PROGRAM THEN WAITS FOR AN ASCII 'I' + DIVER
               322 ;   BY THE DOWNLINE PROG. THEN IT WAITS FOR 4 PLACE
               323 ;   HEX ADDRESS GIVEN BY "UKB" STATEMENT IN
               324 ;   ASSEMBLED PROGRAM. THEN IT RECIEVES 2 PLACE HEX
               325 ;   DATA AS FAST AS POSSIBLE UNTIL AN ASCII "ESCAPE"
               326 ;   CHARACTER IS RECIEVED. RETURNING TO MONITOR
               327 ;   AFTER THAT.
               328 ;
     007F      329          UNDEF   EQU     7FH
     0000      330          ZERO    EQU     00H
     0040      331          SIXTY4  EQU     40H
     0030      332          FORTY8  EQU     30H
     0037      333          FIFTY5  EQU     37H
     001B      334          ESCAPE  EQU     1BH
     002F      335          IGNOFF  EQU     2FH
     0049      336          ASCII   EQU     49H
               337 ;
               338 ;
               339 ; PUT ALL THE ASSEMBLER DECODED CONSTANTS INTO REGISTERS
               340 ;
               341 ;
1948 AF        342 IBLK:    XRA     A
1949 32 0170   343          STA     SUM1
194C 06 40     344 IBLK:    MVI     C,    SIXTY4
194E 16 30     345          MVI     D,    FORTY8
1950 1E 37     346          MVI     E,    FIFTY5
1952 AF        347          XRA     A
1953 32 0170   348          STA     CSUM
1956 32 2970   349          STA     BLKCNT
1959 CD 0643   350          CALL    BLANK           ;BLANK THE LED DISPLAY
```

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                        351 ;
                        352 ; NOW GET THE COMMAND AND STARTING ADDRESS
                        353 ;
                        354 ;
1955 3A 2970            355 TRYAGN:   LDA     BLKCNT
1958 3C                 356           INR     A
1959 32 2970            357           STA     BLKCNT
195C 32 2980            358           STA     LED1
195F CD 3A1B            359           CALL    CI2             ;GET MSB N--ASCII IN A
1962 E6 7F              360           ANI     UNE27
1964 FE 1B              361           CPI     ESCAPE          ;IF THIS IS AN ESCAPE
1966 CA 111A            362           JZ      LEAVE           ;   THEN WE ARE DONE
1969 FE 2F              363           CPI     IGNORE          ;   ELSE IF CHAR IS IGNORABLE
196B DA 3E1A            364           JC      TRYAGN          ;        THEN GET ANOTHER CHAR
196E FE 47              365           CPI     ASCIIF          ;        ELSE IF CHAR IS NOT I
1970 C2 111A            366           JNZ     LEAVE           ;             THEN SOME ERROR
1973 CD 3A1B            367           CALL    CI2             ;             ELSE CONTINUE
1976 E6 7F              368           ANI     UNE27           ;MASK MSB
1978 CD 001A            369           CALL    TRANSLATE       ;HEX IN A
197B 07                 370           RLC
197C 07                 371           RLC
197D 07                 372           RLC                     ;SHIFT LEFT 4
197E 07                 373           RLC
197F 67                 374           MOV     H,A             ;PUT IN H
1980 CD 3A1B            375           CALL    CI2             ;GET LEAST SIG BYTE N
1983 E6 7F              376           ANI     UNE27           ;MASK
1985 CD 001A            377           CALL    TRANSLATE
1988 84                 378           ADD     H               ;
1989 67                 379           MOV     H, A            ;HIGH BYTE COMPLETE
198A CD 3A1B            380           CALL    CI2             ;DO THE SAME WITH LOW BYTE
198D E6 7F              381           ANI     UNE27
198F CD 001A            382           CALL    TRANSLATE
1992 07                 383           RLC
1993 07                 384           RLC
1994 07                 385           RLC
1995 07                 386           RLC
1996 6F                 387           MOV     L,A
1997 CD 3A1B            388           CALL    CI2
199A E6 7F              389           ANI     UNE27
199C CD 001A            390           CALL    TRANSLATE
199F 85                 391           ADD     L
19A0 6F                 392           MOV     L, A
                        393 ;
                        394 ; FIRST ADDRESS NOW IN HL
                        395 ;
                        396 ;
                        397 ;
19A1 CD 3A1B            398 RD:       CALL    CI2
19A4 E6 7F              399           ANI     UNE27           ;READ AND IGNORE CHARACTERS UNTIL CARRIAGE
19A6 FE 0A              400           CPI     LF              ;RETURN
19A8 C2 A81A            401           JNZ     RD
19AB 3A 0170            402           LDA     CSUM
19AE 4F                 403           MOV     C,A
19AF CD 201A            404           CALL    CO2             ;SEND OUT CHECKSUM
19B2 AF                 405           XRA     A
19B3 32 0170            406           STA     CSUM            ;AND ZERO CHECKSUM
19B6 06 01              407           MVI     B,    01H
19B8 0E 40              408           MVI     C,    SIXTY4    ;RESET THE C REGISTER
                        409 ;
                        410 ; REGISTER B SERVES AS A HIGH-LO BYTE FLAG
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                        411 ;
                        412 ;
                        413 ; YOU REPEAT UNTIL THE INPUT CHARACTER IS ESCAPE.  NOTE THE ROUTINE
                        414 ; IGNORES CARRIAGE RETURNS,SPACES,LINEFEEDS, ETC.
                        415 ;
                        416 ;
19C1 CD 3A1B    417 GETBYTE:  CALL    C12             ;INPUT IN A
19C4 E6 7F      418           ANI     0X7F            ;MASK OFF MOST SIG BIT
19C6 FE 1B      419           CPI     ESCAPE          ;IF THE INPUT CHAR IS ESCAPE
19C8 CA E519    420           JZ      CKSUM           ;  THEN GET THE HEX ADDR.
19CB FE 2F      421           CPI     IGNORE          ;  ELSE IF WE HAVE AN IGNORABLE CHAR
19CD DA C119    422           JC      GETBYTE         ;       THEN IGNORE IT
19D0 CD 001A    423           CALL    TRANSLATE       ;       ELSE PROCESS FURTHER
19D3 05         424           DCR     B               ;CHANGE B
19D4 CC 001A    425           CZ      MOVER           ;IF B=0 ZERO HIGH BYTE, DO SHIFT
                426                                   ;NOTE--MOVER CLEARS (HL) AND SHIFTS A
                427                                   ;FOUR LEFT, SETS B TO ONE
19D7 86         428           ADD     M               ;ADD A TO (HL)
19D8 77         429           MOV     M,  A           ;PUT RESULT IN (HL)
19D9 05         430           DCR     B               ;CHANGE B
19DA CA C117    431           JZ      GETBYTE         ;IF B IS ZERO WE HAVE DONE THE HIGH BYTE
19DD 06 01      432           MVI     B,  01H         ;ELSE WE DID LOW BYTE,SET FLAG
19DF 23         433           INX     H               ;POINT TO NEXT LOCATION
19E0 C3 C119    434           JMP     GETBYTE         ;AND DO IT AGAIN
                435 ;
19E3 3A 0170    436 CKSUM:    LDA     CSUM
19E6 4F         437           MOV     C,A
19E7 AF         438           XRA     A               ;SEND AND CLEAR CHECKSUM
19E8 32 0170    439           STA     CSUM
19EB 3A 0070    440           LDA     SCRAT
19EE FE 00      441           CPI     00H             ; SEE IF ENTERED BY JUMBLE
19F0 C2 F819    442           JNZ     RESTOR
19F3 4D         443           MOV     C , L
19F4 7D         444           MOV     A , L
19F5 CD B11B    445           CALL    HXD
19F8 CD 201B    446 RESTOR:   CALL    CO2             ; SEND LOWER ADDRESS BYTE
19FB 0E 40      447           MVI     C , SIXTY4      ; RESTORE C
19FD C3 5C19    448           JMP     TRYAGN          ; WAIT FOR NEXT IXXXX
                449 ;
                450 ;
                451 ; BELOW SUBROUTINE TRANSLATES A VALID ASCII CHARACTER INTO
                452 ; THE HEX EQUIVALENT IN LOWER FOUR BITS OF A.
                453 ;
                454 ;
1A00 B9         455 TRANSLATE: CMP    C               ;IS THE ASCII A NUMBER?
1A01 DA 0A1A    456           JC      NUMBER          ;IF SO, JUMP
1A04 D3         457           SUB     E               ;  ELSE WE HAVE A LETTER, CONVERT
1A05 C9         458           RET                     ;AND RETURN
1A06 D2         459 NUMBER:   SUB     D               ;WE HAVE A NUMBER
1A07 C9         460           RET
                461 ;
                462 ;
                463 ; BELOW SUBROUTINE CLEARS (HL), SHIFTS A LEFT 4, SETS B TO ONE
                464 ;
                465 ;
1A08 3E 00      466 MOVER:    MVI     M,  ZERO        ;CLEAR (HL)
1A0A 07         467           RLC
1A0B 07         468           RLC
1A0C 07         469           RLC
1A0D 07         470           RLC
```

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1A0E 3E 01   471            MVI    A,   01H
1A10 C9      472            RET
             473 ;
1A11 3E 01   474 LEAVE:     MVI    A,01H
1A13 32 004F 475            STA    LEDB                ;SIGNAL OPERATOR WE ARE DONE
1A16 C9      476            RET                        ;JUMP HEADLONG INTO PROGRAM
             477 ;
             478 ;   THIS IS TO SET TIMER UP FOR 300 BAUD , THEN JUMP
             479 ;   TO IBLK WHICH ACCEPTS DATA FROM THE UART
             480 ;
1A17 3E 76   481 IBLK:      MVI    A,   76H            ; SET MODE FOR COUNTER 1
1A19 D3 7B   482            OUT    7BH
1A1B 3E 99   483            MVI    A, 99H              ; LOAD IN 0199H
1A1D D3 79   484            OUT    79H                 ; (409 BASE 10)
1A1F 3E 01   485            MVI    A, 01H              ; FOR 300 BAUD
1A21 D3 79   486            OUT    79H                 ; DIVIDE BY 'N'
1A23 3E 01   487            MVI    A , 01H
1A25 32 0070 488            STA    SCRAT               ; SET UP FLAG FOR
1A28 C3 4E19 489            JMP    IBLK                ; CHECKSUM
             490 ;
             491 ; MOVE A BLOCK OF MEMORY.
             492 ;
             493 ; THIS ROUTINE EXPECTS THREE HEXADECIMAL PARAMETERS FROM THE
             494 ; CONSOLE. THE FIRST AND SECOND PARAMETERS ARE THE BOUNDS OF
             495 ; THE MEMORY AREA TO BE MOVED. THE THIRD PARAMETER IS THE
             496 ; STARTING ADDRESS OF THE DESTINATION AREA.
             497 ;
1A2B 0C      498 MOVE:  INR     C                   ; GET THREE ADDRESSES
1A2C CD 7318 499        CALL    EXPK
1A2F C1      500        POP     B                   ; DESTINATION
1A30 D1      501        POP     D                   ; SOURCE END
1A31 E1      502        POP     H                   ; SOURCE BEGIN
1A32 7E      503 MVO:   MOV     A,M                 ; GET A DATA BYTE
1A33 02      504        STAX    B                   ; STORE AT DESTINATION
1A34 03      505        INX     B
1A35 CD A71A 506        CALL    HILO                ; TEST FOR COMPLETION
1A38 D2 321A 507        JNC     MVO
1A3B C3 6C1B 508        JMP     RSTART
             509     ;
             510     ;
             511     ; SUBSTITUTE MEMORY CONTENTS ROUTINE.
             512     ;
             513     ; THIS ROUTINE EXPECTS ONE PARAMETER FROM THE CONSOLE, FOLLOWED
             514     ; BY A SPACE. THE PARAMETER IS INTERPRETED AS A MEMORY LOCATION
             515 ; AND THE ROUTINE WILL DISPLAY THE CONTENTS OF THAT LOCATION,
             516 ; FOLLOWED BY A DASH (-).  TO MODIFY MEMORY, TYPE IN THE NEW DATA
             517 ; FOLLOWED BY A SPACE OR A CARRIAGE RETURN.  IF NO MODIFICATION
             518 ; OF THE LOCATION IS REQUIRED, TYPE ONLY A SPACE OR CARRIAGE RETURN.
             519 ; IF A SPACE WAS LAST TYPED, THE NEXT MEMORY LOCATION WILL BE DISPLAYED
             520 ; AND MODIFICATION OF IT IS ALLOWED.  IF A CARRIAGE RETURN WAS ENTERED,
             521 ; THE COMMAND IS TERMINATED.
             522 ;
1A3E 0D      523 SUBS:  MCR     C
1A3F CD 7318 524        CALL    EXPK                ; GET ONE ADDRESS
1A42 CB E41B 525        CALL    PZC
1A45 DA 041B 526        JC      LEK
1A48 E1      527        POP     H
1A49 7E      528 SUB1:  MOV     A,M
1A4A CD B41B 529        CALL    LBYTE               ; DISPLAY DATA
1A4D 0E 2D   530        MVI     C,'-'
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1A4C CD 1C1B 531        CALL    LU.
1A52 CD*E11B 532        CALL    PCHK
1A55 DA 6C1A 533        JC      MSTART          # CR ENTERED RETURN TO COMMAND MODE
1A58 CA CD1A 534        JZ      SU1             # SPACE ENTERED SPACE BY
1A5B E5      535        PUSH    H               # SAVE MEMORY ADDRESS
1A5C CD 9F1B 536        CALL    EXP             # GET NEW VALUE
1A5F D1      537        POP     D               # E = VALUE
1A60 E1      538        POP     H               # RESTORE MEMORY ADDRESS
1A61 73      539        MOV     M,E             # STORE NEW VALUE
1A62 7B      540        MOV     A,E             # TEST DELIMITER
1A63 FE 0D   541        CPI     CR
1A65 CA 6C1A 542        JZ      MSTART          # CR ENTERED AFTER LAST SUBSTITUTION
1A68 23      543 SU1:   INX     H
1A69 C3 491A 544        JMP     SUB             # RESTORE HIGH ADDRESS
             545 ;
             546 ;
             547 ;
             548 ; EXAMINE AND MODIFY CPU REGISTERS.
             549 ;
             550 ; THIS ROUTINE ALLOWS THE OPERATOR TO EXAMINE AND/OR MODIFY
             551 ; THE CONTENTS OF THE USER PROGRAM'S REGISTERS.  THE REGISTER
             552 ; VALUES WERE STORED AS A RESULT OF A PREVIOUS BREAKPOINT AND
             553 ; WILL BE RESTORED TO THE USER PROGRAM DURING A SUBSEQUENT  G
             554 ; COMMAND.
             555 ;
1A6C CD 5C1C 556 XR:    CALL    II              # GET REGISTER IDENTIFIER
1A6F 21 781C 557        LXI     H,ACTBL         #POINT TO ACCESS TABLE
1A72 FE 0D   558        CPI     CR              #IF CR= DO ALL
1A74 CA B51A 559        JZ      X6              # FULL REGISTER DISPLAY
1A77 BE      560 X0:    CMP     M
1A78 CA 881A 561        JZ      X1
1A7B F5      562        PUSH    PSW             # SAVE THE CHARACTER
1A7C 7E      563        MOV     A,M
1A7D B7      564        ORA     A               # TEST FOR END OF TABLE
1A7E FA 041B 565        JM      LER
1A81 23      566        INX     H
1A82 23      567        INX     H
1A83 23      568        INX     H
1A84 F1      569        POP     PSW
1A85 C3 771A 570        JMP     X0
1A88 CD 101B 571 X1:    CALL    BLK
1A8B 23      572 X2:    INX     H
1A8C 7E      573        MOV     A,M             # DISPLACEMENT
1A8D EB      574        XCHG                    # SAVE HL IN DE(HL = POINTER TO ACTBL)
1A8E 6F      575        MOV     L,A
1A8F 26 00   576        MVI     H,0
1A91 39      577        DAD     SP
1A92 EB      578        XCHG                    # RESTORE HL
1A93 23      579        INX     H
1A94 4E      580        MOV     B,M             # PRECISION
1A95 23      581        INX     H               # POINT AT NEXT REGISTER IDENTIFIER
1A96 1A      582        LDAX    D               # 8/16 BIT DISPLAY AND MODIFICATION
1A97 CD 9F1B 583        CALL    LBYTE           # MSB OF 16 BIT REG= ALL OF 8 BIT REG
1A9A 05      584        DCR     B
1A9B CA A31A 585        JZ      X3              # 8 BIT DISPLAY
1A9E 1B      586        DCX     D
1A9F 1A      587        LDAX    D
1AA0 CD 9F1B 588        CALL    LBYTE           # LSB OF 16 BIT REG
1AA3 04      589 X3:    INR     B
1AA4 0E 2D   590        MVI     C,'-'
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1AA6 CD 1118 591        CALL    CU
1AA9 CD E11B 592        CALL    PCHR            ; SKIP IF NULL ENTRY
1AAC DA E01B 593        JC      MSTART          ; IF ENTERED RETURN TO COMMAND MODE
1AAF CA C71A 594        JZ      X5
1AB2 E5      595        PUSH    H               ; SAVE POINTER TO ACTN
1AB3 C5      596        PUSH    B               ; SAVE PRECISION
1AB4 CD 9F1B 597        CALL    EXP             ; GET NEW REG VALUE
1AB7 E1      598        POP     H
1AB8 F1      599        POP     PSW             ; A = PRECISION
1AB9 C5      600        PUSH    B               ; B = DELIMITER CHAR
1ABA F5      601        PUSH    PSW             ; A = PRECISION
1ABB 7D      602        MOV     A,L
1ABC 12      603        STAX    D               ; STORE LSB IN REGISTER AREA
1ABD C1      604        POP     B               ; RETRIEVE PRECISION
1ABE 05      605        DCR     B
1ABF CA CB1A 606        JZ      X4              ; 8 BITS ONLY
1AC2 13      607        INX     D
1AC3 7C      608        MOV     A,H
1AC4 12      609        STAX    D               ; STORE MSB IN REGISTER AREA
1AC5 C1      610 X4:    POP     B               ; RETRIEVE DELIMITER CHAR
1AC6 E1      611        POP     H
1AC7 7E      612 X5:    MOV     A,M             ; TEST FOR END OF TABLE
1AC8 B7      613        ORA     A
1AC9 FA E01B 614        JM      MSTART
1ACC 78      615        MOV     A,B             ; TEST DELIMITER
1ACD FE 0D   616        CPI     CR
1ACF CA E01B 617        JZ      MSTART
1AD2 C3 B81A 618        JMP     X2
1AD5 CD E41B 619 X6:    CALL    CRLF
1AD8 CD 101B 620 X7:    CALL    BLK             ; OUTPUT A SPACE
1ADB 7E      621        MOV     A,M             ; GET THE CHARACTER
1ADC 23      622        INX     H               ; POINT AT DISPLACEMENT
1ADD B7      623        ORA     A               ; SET CONDITION CODES
1ADE FA E01B 624        JM      MSTART          ; ALL DONE
1AE1 4F      625        MOV     C,A
1AE2 CD 121B 626        CALL    CO              ; PRINT CHARACTER
1AE5 0E 3D   627        MVI     C,'='
1AE7 CD 121B 628        CALL    CO              ; PRINT EQUAL SIGN
1AEA 7E      629        MOV     A,M             ; FETCH DISPLACEMENT
1AEB 23      630        INX     H               ; POINT AT PRECISION
1AEC EB      631        XCHG                    ; SAVE HL IN DE
1AED 6F      632        MOV     L,A
1AEE 26 00   633        MVI     H,0
1AF0 39      634        DAD     SP              ; COMPUTE ADDRESS OF VALUE
1AF1 EB      635        XCHG                    ; HL = CURRENT TABLE ADDRESS
                                                   DE = MEMORY ADDRESS
             636 ;
1AF2 46      637        MOV     B,M             ; FETCH PRECISION
1AF3 23      638        INX     H               ; POINT TO NEXT DISPLAY
1AF4 1A      639        LDAX    D               ; GET LSB OF DATA
1AF5 CD BF1B 640        CALL    LBYTE           ; DISPLAY IT
1AF8 05      641        DCR     B
1AF9 CA D91A 642        JZ      X7              ; 8 BIT PRECISION, ALL DONE
1AFC 1B      643        DCX     D               ; POINT TO MSB OF 16 BIT VALUE
1AFD 1A      644        LDAX    D               ; FETCH IT
1AFE CD BF1B 645        CALL    LBYTE           ; DISPLAY IT
1B01 C3 D91A 646        JMP     X7              ; CONTINUE
             647 ;
             648 ; ERROR EXIT.
             649 ;
             650 ; THIS ABNORMAL EXIT IS EXECUTED FOR ALL MONITOR ERROR CONDITIONS.
```

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                    651 ; THE STACK POINTER VALUE IS RECOMPUTED BECAUSE OF THE UNKNOWN STATE
                    652 ; OF THE PROCESSOR AS THE RESULT OF A COMMAND OR DATA ERROR.
                    653 ;
1804 21 E870        654 CLR:  LXI     H,STACK-TEMPUK-EXIT-8  ;SET STACK POINTER
1807 F9             655       SPHL                     ; RESET STACK POINTER ON ERROR RETURN
1808 0E 3F          656       MVI     C,'?'
180A CD 1218        657       CALL    CO
180D C3 0C1B        658       JMP     RSTART
                    659 ;
                    660 ; SUBROUTINES
                    661 ;
1810 0E 20          662 BLK:  MVI     C,' '          ; PRINT A BLANK
                    663 ;
                    664 ; EXTERNALLY REFERENCED ROUTINE
                    665 ; CONSOLE OUTPUT CODE, VALUE EXPECTED IN C
                    666 ; A=FLAGS,C MODIFIED
                    667 ; STACK USAGE: 2 BYTES
                    668 ;
1812 00             669 CO:   NOP                      ; CONSOLE OUTPUT
1813 3A 0168        670 TTYOUT: LDA     S1DC           ; CONSOLE = TTY
1816 E6 01          671       ANI     STRDY
1818 CA 1813        672       JZ      TTYOUT         ; LOOP UNTIL READY
181B 79             673       MOV     A,C
181C 32 0068        674       STA     S1D            ; OUTPUT CHARACTER
181F C9             675       RET                    ; RETURN
                    676 ;
1820 00             677 CO2:  NOP
1821 3A 0160        678 TOUT: LDA   S1DC2
1824 E6 01          679       ANI   STRDY
1826 CA 2118        680       JZ    TOUT
1829 79             681       MOV   A,C
182A 32 0060        682       STA   S1D2
182D C9             683       RET
                    684 ;
                    685 ; EXTERNALLY REFERENCED ROUTINE
                    686 ; CONSOLE INPUT CODE, VALUE RETURNED IN A
                    687 ; A= FLAGS MODIFIED
                    688 ; STACK USAGE: 2 BYTES
                    689 ;
     182E           690 TTYIN EQU   $              ; CONSOLE INPUT AND TTYIN
182E 3A 0168        691 CI:   LDA     S1DC         ; TTY STATUS PORT
1831 E6 02          692       ANI     SRNDY        ; CHECK FOR DATA AVAILABLE
1833 CA 2E18        693       JZ      TTYIN
1836 3A 0068        694       LDA     S1D          ; READ THE CHARACTER
1839 C9             695 CI0:  RET
                    696 ;
     183A           697 TYIN  EQU     $
183A 3A 0160        698 CI2:  LDA     S1DC2        ; TTY STATUS PORT
183D E6 02          699       ANI     SRNDY        ; CHECK FOR DATA AVAILABLE
183F CA 3A18        700       JZ      TYIN
1842 3A 0060        701       LDA     S1D2         ; READ THE CHARACTER
1845 E5             702       PUSH    H
1846 21 0170        703       LXI     H,CSUM
1849 32 1370        704       STA     TEMP         ;SAVE CHARACTER READ
184C 86             705       ADD     M            ;ADD IT INTO THE CHECKSUM
184D 77             706       MOV     M,A          ;STORE IN CSUM
184E E1             707       POP     H
184F 3A 1370        708       LDA     TEMP         ;AND LEAVE CHARACTER IN A
1852 C9             709       RET
                    710 ;
```

```
                        ;11 ; 1.0 MS DELAY
                        ;12 ;
1B53 C5                 ;13 DELAY: PUSH    B
1B54 06 FF              ;14        MVI     B,0FFH
1B56 05                 ;15 DL0:   DCR     B
1B57 C2 561B            ;16        JNZ     DL0
1B5A C1                 ;17        POP     B
1B5B C9                 ;18        RET                     ; RETURN
                        ;19 ;
                        ;20 ; CONVERT 4 BIT HEX VALUE TO ASCII CHARACTER
                        ;21 ; INPUT:               - 0...0FH
                        ;22 ; OUTPUT:      - 30H...39H, 41H...46H
                        ;23 ;
1B5C C6 90              ;24 CONV:  ADI     90H             ; SET UP A SO THAT A-F CAUSE CARRY
1B5E 27                 ;25        DAA
1B5F CE 40              ;26        ACI     40H             ; ADD IN CARRY AND ADJUST UPPER NIBBLE
1B61 27                 ;27        DAA
1B62 4F                 ;28        MOV     C,A       @
1B63 C9                 ;29        RET                     ; RETURN
                        ;30 ;
                        ;31 ; TYPE CARRIAGE RETURN AND LINE FEED ON CONSOLE
                        ;32 ;
1B64 0E 0D              ;33 CRLF:  MVI     C,CR            ; <CR>
1B66 CD 121B            ;34        CALL    CO
1B67 0E 0A              ;35        MVI     C,LF            ; <LF>
1B6A CD 121B            ;36        CALL    CO
1B6C 0E 00              ;37        MVI     C,0             ; <NULL> FOR RETURN
1B70 C3 121B            ;39        JMP     CO
                        ;39 ;
                        ;40 ; EVALUATE EXPRESSION: <EXPR>,<EXPR>,<EXPR>
                        ;41 ;
                        ;42 ; THE C REGISTER CONTAINS THE NUMBER OF PARAMETERS REQUIRED
                        ;43 ; (1,2, OR 3).  PARAMETERS ARE RETURNED ON THE STACK.
                        ;44 ;
1B73 21 0000            ;45 EXPR:  LXI     H,0             ; INITIAL VALUE OF PARAMETER
1B76 CD 5C1C            ;46 EX0:   CALL    TI              ; GET A CHARACTER
1B79 47                 ;47 EX1:   MOV     B,A             ; SAVE DELIMITER CHARACTER
1B7A CD CF1B            ;48        CALL    NIBBLE          ; CONVERT TO HEX
1B7D DA 891B            ;49        JC      EX2             ; NOT LEGAL CHAR, TREAT AS DELIMITER
1B80 29                 ;50        DAD     H               ; *2
1B81 29                 ;51        DAD     H               ; *4
1B82 29                 ;52        DAD     H               ; *8
1B83 29                 ;53        DAD     H               ; *16
1B84 B5                 ;54        ORA     L
1B85 6F                 ;55        MOV     L,A
1B86 C3 761B            ;56        JMP     EX0             ; GET ANOTHER CHARACTER
1B89 E3                 ;57 EX2:   XTHL                    ; GET RETURN ADDRESS OFF STACK
                        ;58 ;                              ; PUT HL ON
1B8A E5                 ;59        PUSH    H               ; REPLACE RETURN ADDRESS
1B8B 78                 ;60        MOV     A,B
1B8C CD E41B            ;61        CALL    P2C             ; TEST DELIMITER CHARACTER
1B8F D2 971B            ;62        JNC     EX3
1B92 0D                 ;63        DCR     C               ; CR ENTERED
1B93 C2 041B            ;64        JNZ     LER             ; TOO FEW PARAMS
1B96 C9                 ;65        RET
1B97 C2 041B            ;66 EX3:   JNZ     LER             ; ILLEGAL DELIMITER
1B9A 0D                 ;67        DCR     C
1B9B C2 731B            ;68        JNZ     EXPR
1B9E C9                 ;69        RET
1B9F 0E 01              ;70 EXP:   MVI     C,1
```

```
1BA1 21 0000    771         LXI     H,0
1BA4 C3 791B    772         JMP     EX1
                773 ;
                774 ; COMPARE HL WITH DE:
                775 ; IF HL < DE THEN CARRY = 0;
                776 ; IF HL = DE THEN CARRY = 0;
                777 ; IF HL > DE THEN CARRY = 1;
                778 ;
1BA7 23         779 HILO:   INX     H               ; BUMP HL
1BA8 7C         780         MOV     A,H             ; TEST FOR HL = 0
1BA9 B5         781         ORA     L
1BAA 37         782         STC
1BAB C8         783         RZ
1BAC 7B         784         MOV     A,E             ; DE - HL, SET/RESET CARRY
1BAD 95         785         SUB     L
1BAE 7A         786         MOV     A,D
1BAF 9C         787         SBB     H
1BB0 C9         788         RET                     ; RETURN
                789 ;
                790 ; CONVERT NIBBLE IN A-REGISTER TO ASCII IN A-REGISTER
                791 ; AND PRINT ON CONSOLE DEVICE
                792 ;
1BB1 CD 5C1B    793 HXD:    CALL    CONV
1BB4 C3 121B    794         JMP     CO
                795 ;
                796 ; PRINT CONTENTS OF HL IN HEX ON CONSOLE DEVICE
                797 ;
1BB7 7C         798 LAHX:   MOV     A,H             ; PRINT MSB
1BB8 CD B91B    799         CALL    LBYTE
1BBB 7D         800         MOV     A,L             ; PRINT LSB
1BBC C3 B91B    801         JMP     LBYTE
                802 ;
                803 ; LIST A BYTE AS 2 ASCII CHARACTERS
                804 ;
1BBF F5         805 LBYTE:  PUSH    PSW             ; SAVE A COPY OF A
1BC0 0F         806         RRC
1BC1 0F         807         RRC
1BC2 0F         808         RRC
1BC3 0F         809         RRC
1BC4 E6 0F      810         ANI     0FH             ; UPPER 4 BITS
1BC6 CD B11B    811         CALL    HXD
1BC9 F1         812         POP     PSW             ; RETRIEVE ORIGINAL VALUE
1BCA E6 0F      813         ANI     0FH             ; LOWER 4 BITS
1BCC C3 B11B    814         JMP     HXD
                815 ;
                816 ;
                817 ; DECODE ASCII CHAR IN A-REGISTER INTO HEX DIGIT IN A-REGISTER
                818 ; FILTER OUT ALL CHARACTERS NOT IN THE SEQUENCE (0...9,A...F).
                819 ; RETURN CARRY = 1 FOR ILLEGAL CHARACTERS.
                820 ;
1BCF D6 30      821 NIBBLE: SUI     '0'
1BD1 D8         822         RC                      ; FILTER OUT 0-2FH
1BD2 C6 E9      823         ADI     '0'-'G'
1BD4 D8         824         RC                      ; FILTER OUT 47H-0FFH
1BD5 C6 06      825         ADI     6
1BD7 F2 DC1B    826         JP      NIO             ; TAKE BRANCH FOR A-F
1BDA C6 07      827         ADI     7               ; FILTER OUT 3AH-40H
1BDC D8         828         RC
1BDD C6 0A      829 NIO:    ADI     10
1BDF B7         830         ORA     A               ; CLEAR ERROR FLAG
```

```
1BE0 C9         831         RET                     ; RETURN
                832 ;
                833 ;
                834 ; TEST FOR NULL INPUT PARAMETER
                835 ;
1BE1 CD 5C1C    836 PCHK:   CALL    TI              ; GET A CHARACTER
1BE4 FE 20      837 PCC:    CPI     ' '
1BE6 C8         838         RZ
1BE7 FE 2C      839         CPI     ','
1BE9 C8         840         RZ
1BEA FE 0D      841         CPI     CR
1BEC 37         842         STC
1BED 3F         843         CMC
1BEE C0         844         RNZ
1BEF 37         845         STC
1BF0 C9         846         RET
                847 ;
                848 ; RESTART 1 CODE (PROGRAMMED BREAKPOINT).
                849 ;
                850 ; THIS ROUTINE IS ENTERED VIA A RESTART 1 (RST 1) INSTRUCTION.
                851 ; THE INSTRUCTION IS ENCOUNTERED EITHER IN THE USER PROGRAM (AS
                852 ; A BREAKPOINT) OR IS INPUT VIA A CONSOLE INTERRUPT.  THIS
                853 ; ROUTINE SAVES THE STATE OF THE CALLING PROCESS AND TURNS CONTROL
                854 ; OVER TO THE MONITOR.
                855 ;
1BF1 E5         856 RESTART:  PUSH    H               ; SAVE MACHINE STATE
1BF2 D5         857           PUSH    D
1BF3 C5         858           PUSH    B
1BF4 F5         859           PUSH    PSW
1BF5 21 EE70    860           LXI     H,STACK-(ENDX-EXIT)
1BF8 EB         861           XCHG
1BF9 21 0A00    862           LXI     H,10
1BFC 39         863           DAD     SP              ; COMPUTE ORIGINAL STACK POINTER
1BFD 06 04      864           MVI     B,4             ; COUNT FOR TRANSFER OF MACHINE STATE
                865 ;                                 ; TO STORAGE (MOVE THE STACK)
1BFF EB         866           XCHG
1C00 2B         867 RST0:   DCX     H
1C01 72         868         MOV     M,D
1C02 2B         869         DCX     H
1C03 73         870         MOV     M,E
1C04 D1         871         POP     D
1C05 05         872         DCR     B
1C06 C2 001C    873         JNZ     RST0
1C09 C1         874         POP     B               ; GET OLD PC = H,C; OLD ME = D,E
1C0A 0B         875         DCX     B               ; DECREMENT TO POINT AT TRAPPED CODE
1C0B F9         876         SPHL                    ; NEW STACK VALUE
1C0C 21 1400    877         LXI     H,TLOC
1C0F 39         878         DAD     SP
1C10 7E         879         MOV     A,M             ; TEST IF THIS IS A PROGRAMMED RESTART
1C11 91         880         SUB     C               ; OR A CONSOLE RESTART
1C12 23         881         INX     H
1C13 C2 181C    882         JNZ     RST1
1C16 7E         883         MOV     A,M
1C17 90         884         SUB     B
1C18 CA 291C    885         JZ      RST3
1C1B 23         886 RST1:   INX     H
1C1C 23         887         INX     H
1C1D 7E         888         MOV     A,M
1C1E 91         889         SUB     C
1C1F C2 281C    890         JNZ     RST2
```

```
1C22 23       897       INX     H
1C23 7E       898       MOV     A,M
1C24 90       899       SUB     B
1C25 CA 271C  900       JZ      RST3
1C28 03       901 RST2: INX     B
1C29 21 0400  902 RST3: LXI     H,LLOC
1C2C 39       903       DAD     SP
1C2D 73       904       MOV     M,E
1C2E 23       905       INX     H
1C2F 72       906       MOV     M,D             ; SAVE OLD HL
1C30 23       907       INX     H
1C31 23       908       INX     H
1C32 71       909       MOV     M,C             ; SAVE OLD PC
1C33 23       910       INX     H
1C34 70       911       MOV     M,B
1C35 C5       912       PUSH    B
1C36 0E 2A    913       MVI     C,'*'
1C38 CD 1218  914       CALL    CO
1C3B E1       915       POP     H               ; RETRIEVE OLD PC FOR DISPLAY
1C3C CD 1718  916       CALL    LADR            ; DISPLAY PC
1C3F 21 1400  917       LXI     H,FLOC          ; CLEAR TRAPS
1C42 39       918       DAD     SP
1C43 1E 02    919       MVI     D,2             ; SET COUNT FOR TWO TRAPS
1C45 4E       920 RST4: MOV     C,M             ; GET LSB OF ADDRESS
1C46 36 00    921       MVI     M,0             ; CLEAR MEMORY
1C48 23       922       INX     H
1C49 46       923       MOV     B,M             ; GET MSB OF ADDRESS
1C4A 36 00    924       MVI     M,0
1C4C 23       925       INX     H
1C4D 79       926       MOV     A,C
1C4E B0       927       ORA     B               ; TEST FOR VALID TRAP
1C4F CA 541C  928       JZ      RST5            ; ADDRESS = 0, NO TRAP TO RESTORE
1C52 7E       929       MOV     A,M             ; GET OPCODE BYTE
1C53 02       930       STAX    B               ; REPLACE IT
1C54 23       931 RST5: INX     H               ; POINT TO NEXT TRAP ADDRESS
1C55 15       932       DCR     D
1C56 C2 451C  933       JNZ     RST4            ; REPEAT FOR TRAP 2
1C59 C3 0C18  934       JMP     RSTART
              935 ;
              936 ; INPUT FROM CONSOLE, ECHOED AND RETURNED IN A
              937 ;
1C5C CD 2E18  938 CI:   CALL    CI
1C5F E6 7F    939       ANI     7FH
1C61 C5       940       PUSH    B
1C62 4F       941       MOV     C,A
1C63 CD 1218  942       CALL    CO
1C66 79       943       MOV     A,C
1C67 C1       944       POP     B
1C68 C9       945       RET                     ; RETURN
              946 ;
              947 ; EXIT CODE TEMPLATE, TO BE EXECUTED IN RAM
              948 ;
              949 ;       DB      E       POP D   ; MONITOR WORK STACK ORIGIN
              950 ;       DB      D
              951 ;       DB      C       POP B
              952 ;       DB      B
              953 ;       DB      FLAGS   POP PSW
              954 ;       DB      A
              955 ;       DB      SPL     POP H
              956 ;       DB      SPU     SPHL
```

```
                        951 ;
1C6A D1                 952 EXIT: POP     D                   ; RESTORE DE
1C6B C1                 953       POP     B                   ; RESTORE BC
1C6C F1                 954       POP     PSW                 ; RESTORE A AND FLAGS
1C6D E1                 955       POP     H                   ; RESTORE ORIGINAL STACK VALUE
1C6E F9                 956       SPHL
1C6F FB                 957       EI                          ; ENABLE INTERRUPTS
1C70 21 0000            958 LXIH: LXI     H,XXXXXX            ; RESTORE H+L
     1C70               959 HLX   EQU     LXIH+1              ; LXI H ARGUMENT FIELD
1C72 C3 0000            960 JMPA: JMP     XXXXXX              ; RETURN TO INTERRUPTED CODE
     1C73               961 PCX   EQU     JMPA+1              ; JMP ARGUMENT FIELD
1C75 0000               962 T1A:  DW      0                   ; TRAP 1 ADDRESS
1C77 00                 963       DB      0                   ; TRAP 1 VALUE
1C78 0000               964       DW      0                   ; TRAP 2 ADDRESS
1C7A 00                 965 ENDA: DB      0                   ; TRAP 2 VALUE
     1C7B               966 ENDX  EQU     ENDA+1
                        967 ;
                        968 ; DISPLACEMENT OF REGISTER LOCATION FROM SP (LEVEL 0)
                        969 ;
     0005               970 ALOC  EQU     5
     0003               971 BLOC  EQU     3
     0002               972 CLOC  EQU     2
     0001               973 DLOC  EQU     1
     0000               974 ELOC  EQU     0
     0004               975 FLOC  EQU     4
     0010               976 HLOC  EQU     HLX-EXIT+9
     000F               977 LLOC  EQU     HLX-EXIT+8
     0013               978 PLOC  EQU     PCX-EXIT+9
     0007               979 SLOC  EQU     7
     0014               980 TLOC  EQU     T1A-EXIT+8
                        981 ;
                        982 ;
                        983 ; TABLE FOR ACCESSING REGISTERS
                        984 ; TABLE CONTAINS:
                        985 ;       (1) REGISTER IDENTIFIER
                        986 ;       (2) STACK POINTER DISPLACEMENT
                        987 ;       (3) PRECISION
                        988 ;
1C7B 41                 989 ACTBL: DB      'A',    ALOC,   1
1C7C 05
1C7D 01
1C7E 42                 990        DB      'B',    BLOC,   1
1C7F 03
1C80 01
1C81 43                 991        DB      'C',    CLOC,   1
1C82 02
1C83 01
1C84 44                 992        DB      'D',    DLOC,   1
1C85 01
1C86 01
1C87 45                 993        DB      'E',    ELOC,   1
1C88 00
1C89 01
1C8A 46                 994        DB      'F',    FLOC,   1
1C8B 04
1C8C 01
1C8D 48                 995        DB      'H',    HLOC,   1
1C8E 10
1C8F 01
1C90 4C                 996        DB      'L',    LLOC,   1
```

```
1C91 0F
1C92 01
1C93 4D          997          DB      'M',    MLOC,   2
1C94 10
1C95 02
1C96 50          998          DB      'P',    PLOC,   2
1C97 13
1C98 02
1C99 53          999          DB      'S',    SLOC,   2
1C9A 07
1C9B 02
1C9C FF          000          DB      -1
                 001 ;***************************************************
                 002 ;   THIS IS TO SET UP THE 8253 TIMER FOR THE UART
                 003 ;   AT A 16X , 110 BAUD RATE. THIS IS DONE BY DIVIDING
                 004 ;   THE 2MHZ 8085 CLK BY 1136.
                 005 ;
1C9D 3E 36       006 TIMER:   MVI   A,   TMODE1          ; SET MODE FOR COUNTER 0
1C9F D3 7B       007          OUT   7BH                  ; READ LST. SIG. BYTE THEN
1CA1 3E 60       008          MVI   A,   60H             ; MOST SIG. BYTE;SQUARE WAVE ,
1CA3 D3 7B       009          OUT   7BH                  ; AND BINARY OUTPUT
1CA5 3E 04       010          MVI   A,   04H             ; THEN SEND CONTROL WORD
1CA7 D3 7B       011          OUT   7BH                  ; AND COUNT WORD TO 8253
                 012 ;
                 013 ;       THIS IS FOR SECOND UART
                 014 ;       DIVIDE BY 1120 FOR 110 BAUD   0460H
                 015 ;       DIVIDE BY 409  FOR 300 BAUD   0199H
                 016 ;
1CA9 3E 76       017          MVI   A , TMODE2           ; SET UP MODE FOR TIMER 2
1CAB D3 7B       018          OUT   7BH
1CAD 3E 60       019          MVI   A , 60H
1CAF D3 79       020          OUT   79H
1CB1 3E 04       021          MVI   A , 04H
1CB3 D3 79       022          OUT   79H
1CB5 C9          023          RET
                 024 ;
                 025 ;***********************
                 026 ;
                 027 ;       9511 ARITHMETIC
                 028 ;
                 029 ;***********************
1CB6 EB          030 PADD2:       XCHG            ;ENTRY POINT FOR: (STK) = ((DE)) + ((HL))
1CB7 CD 011D     031              CALL PUSH4
1CBA EB          032              XCHG
1CBB CD 011D     033 PADD1:       CALL PUSH4      ;ENTRY POINT FOR: (STK) = (STK) + ((HL))
1CBE 3E 10       034 PADD:        MVI  A,10H
1CC0 32 0106     035              STA  MATHC
1CC3 C9          036              RET
                 037 ;
1CC4 EB          038 PSUB2:       XCHG            ;ENTRY POINT FOR: (STK) = ((DE)) - ((HL))
1CC5 CD 011D     039              CALL PUSH4
1CC8 EB          040              XCHG
1CC9 C3 CCIC     041              JMP  PSUB1
1CCC CD 011D     042 PSUB1:       CALL PUSH4
1CCF 3E 11       043 PSUB:        MVI  A,APSUB
1CD1 32 0105     044              STA  MATHC
1CD4 C9          045              RET
                 046 ;
1CD5 EB          047 PMUL2:       XCHG            ;ENTRY POINT FOR: (STK) = ((DE)) * ((HL))
1CD6 CD 011D     048              CALL PUSH4
```

```
1CD9 EB          049              XCHG
1CDA CD 011D C50 FMUL1:   CALL    PUSH4       ;ENTRY POINT FOR: (STK) = (STK) * (HL)
1CDD 3E 12       051 FMUL:    MVI   A,FMUL
1CDF 32 0108 052              STA   MATHC
1CE2 C9          053              RET
                 054 ;
1CE3 EB          055 FDIV2:   XCHG            ;ENTRY POINT FOR: (STK) = ((DE)) / ((HL))
1CE4 CD 011D C56              CALL  PUSH4
1CE7 EB          057              XCHG
1CE8 CD 011D C59 FDIV1:   CALL  PUSH4       ;ENTRY POINT FOR: (STK) = (STK) / ((HL))
1CEB 3E 13       05B FDIV:    MVI   A,FDIV
1CED 32 0108 C60              STA   MATHC
1CF0 C9          061              RET
                 062 ;
                 063 ; FLOAT 16 BIT WORD POINTED TO BY HL AND STORE FLOATING POINT WORD ON
                 064 ; THE STACK OF THE 9511. THE 16 BIT WORD IS STORED IN THE USUAL 8085
                 065 ; FORMAT I.E. LSB FIRST.
                 066 ;
1CF1 7E          067 FLOAT:   MOV   A,M       ;SEND OVER THE LSB
1CF2 32 0008 068              STA   MATHD
1CF5 23          069              INX   H       ;SEND OVER THE MSB
1CF6 7E          070              MOV   A,M
1CF7 32 0008 071              STA   MATHD
1CFA 2B          072              DCX   H       ;LEAVE HL UNCHANGED
1CFB 3E 1D       073 FLOATC:  MVI   A,AFLTS   ;SEND OVER THE FLOAT COMMAND
1CFD 32 0108 074              STA   MATHC
1D00 C9          075              RET
                 076 ;
                 077 ; PUSH THE FOUR BYTES OF A FLOATING POINT WORD (USUALLY) ONTO THE 9511
                 078 ; STACK. THE FOUR BYTES ARE IN THE  LEFT TO RIGHT, AND FORMAT I.E. EXPONENT
                 079 ; FIRST FOLLOWED BY MOST SIGNIFICANT BYTE OF THE MANTISSA ETC. THE
                 080 ; LSB OF THE MANTISSA MUST BE PUSHED FIRST.
1D01 23          081 PUSH4:   INX   H
1D02 23          082              INX   H
1D03 23          083              INX   H
1D04 7E          084              MOV   A,M       ;PUSH LSB
1D05 32 0008 085              STA   MATHD
1D08 2B          086              DCX   H
1D09 7E          087              MOV   A,M
1D0A 32 0008 088              STA   MATHD       ;NEXT LEAST SIGNIFICANT BYTE
1D0D 2B          089              DCX   H
1D0E 7E          090              MOV   A,M
1D0F 32 0008 091              STA   MATHD       ;NEXT
1D12 2B          092              DCX   H
1D13 7E          093              MOV   A,M
1D14 32 0008 094              STA   MATHD       ;PUSH MSB
1D17 C9          095              RET               ;HL IS LEFT UNCHANGED
                 096 ;
                 097 ;
1D18 3A 0008 098 POP4:    LDA   MATHD
1D1B 77          099              MOV   M,A       ;POP MSB
1D1C 23          100              INX   H
1D1D 3A 0008 101              LDA   MATHD       ;POP NEXT MOST SIGNIFICANT BYTE
1D20 77          102              MOV   M,A
1D21 23          103              INX   H
1D22 3A 0008 104              LDA   MATHD       ;NEXT
1D25 77          105              MOV   M,A
1D26 23          106              INX   H
1D27 3A 0008 107              LDA   MATHD       ;POP LSB
1D2A 77          108              MOV   M,A
```

```
.522F C3        107             JMP   H               ;H&L NOW POINTS TO NEXT FLOATING LOCATION
1032 C9         110             RET
                111 ;
                112 ;
                113 ;GET STATUS OF AM9511 IN THE ACCUMULATOR
                114 ;
1033 3A 0108    115 RSTAT:      LDA   MATHC           ;GET AM9511 STATUS WORD
1036 FE 80      116             CPI   80H             ;IS IT BUSY?
1038 F8         117             RM                    ;ACCUMULATOR < 80H BUSY BIT NOT SET--RETURN
1039 C3 3D1D    118             JMP   RSTAT           ;ELSE WAIT
                119             ENDM
```

A	0007	ACTBL	1C78	AFADR	0010	AFDIV	0013	AFLAG	0018
AFMUL	0012	AFSUB	0011	ALOC	0005	ASCII	0040	B	0000
BCD	0000	BEG1	1848	BEGIN	1843	BLANK	7320	BLK	1810
BLKCNT	7029	BLOC	0003	C	0001	C1	1B2E	C10	1849
C12	1B3A	CPSUM	1ME3	CLOC	0002	CO	1B12	CO2	1B20
CONV	1B5C	CR	000D	CRLF	1B54	CSUM	7001	D	0002
DELAY	1B53	DIO	1BD1	DI1	1BD7	DISP	1BCC	DLO	1B56
DLOC	0001	DLY	FFFF	E	0005	ELOC	0000	ERRA	1C7A
ERUX	1C7B	ERRE	1B1F	ERTEXT	1B24	ERRM	1B19	ERRO	1B25
ERSUB	1B39	ESCAPE	001B	EXO	1B76	EXI	1B79	EX2	1B87
EX3	1B97	EXP	1B9F	EXIT	1C0Y	EXPA	1B73	FADD	1CBE
FADD1	1CBB	FADD2	1CB5	FDIV	1CEE	FDIV1	1CEB	FDIV2	1CE3
FIO	1BF4	FIFTY5	0037	FILL	1B5D	FLOAT	1CF1	FLOAT2	1CFB
FLOC	0004	FMUL	1CD0	FMUL1	1CDA	FMUL2	1CD5	FORMTB	0030
FSUB	1CCF	FSUB1	1CCC	FSUB2	1CC4	GETBYT	17C1	G09	1918
G01	191E	G02	1936	G03	1940	GOTO	18FE	H	0004
HILO	1BA7	HINIB	1800	HLOC	0010	HLX	1C70	HXD	1881
IBLK	1946	IGNORE	002F	INBLK	1548	JBLK	1A17	JMPA	1C72
L	0005	LADR	1BB7	LBYTE	1BBF	LEAVE	1A11	LED1	4000
LEDB	4F00	LEN	1B04	LF	000A	LLOC	000F	LVER	0008
LX1H	1C6F	M	0008	M3	0003	MATHC	0001	MATHO	0000
MODE	00CE	MOVE	1A2B	MOVER	1A08	MSTAT	1B6C	MSTAT	1B2B
MVO	1A32	MZO	1B00	MIBBLE	1BLF	NOTJ	1B8B	NUMBER	1A06
ONE2	0078	P2C	1BE4	PCHR	1BE1	PCX	1C73	PLOC	0013
PWR4	1D18	PSW	0006	PUSH	1B01	RD	17A6	RESTAR	18F1
RESTOR	19F8	RL1	0030	RST0	1C00	RST1	1C1B	RS111	00CF
RST2	1C2B	RST3	1C2Y	RST4	1C45	RST5	1C54	SLO	0000
SL1	0040	SLRA1	7000	SPTR	0002	SU0	6300	SU02	6000
SU0C	6501	SU0L2	6001	SUXTT4	0040	SLOC	0007	SP	0006
SREM	0004	SREDY	0002	SRUN	0007	STACK	7100	STEP	0001
STRDY	0001	SU0	1A49	SUI	1A68	SUMS	1A3E	T1A	1C75
TBL	18YC	TEMP	7013	TI	1C5C	TIMER	1CYF	TLOC	0014
TRUDE1	003B	TRUDE2	0076	TOUT	1B21	TRANSL	1A00	TXTAUR	195C
TTYIN	1B2E	TTYOUT	1B13	TYIN	1B3A	VERNO	1B1B	VERS	1B11
X0	1A77	X1	1A88	X2	1A8E	X3	1AA3	X4	1AC5
X5	1AL7	X6	1AD5	X7	1ADB	XR	1A6C	XXXXXX	0000
ZERO	0000								

```
2A58          117             DS    2000
2820          120     RX30:   DW     4
              121 ;
              122 ;   LOGICALS AND FLAGS
              123 ;
2824          124     BUBIT:  DS    1
2825          125     DOJ:    DS    1       ;COUNTER FOR DO LOOPS
2826          126     CLOCKM: DS    1       ;CLOCK ALGORITHM FLAG   \  KEEP
2827          127     CROSSM: DS    1       ;CROSS CORRELATION FLAG  \   FLAGS
2828          128     SLOPEM: DS    1       ;SLOPE ALGORITHM FLAG    /     IN THIS
2829          129     SREGM:  DS    1       ;SREG ALGORITHM FLAG     /       ORDER !!!
282A          130     PKMPTR: DS    2       ;POINTER FOR PEAK DATA
282C          131     SCMPTR: DS    2       ;SCHEDULER POINTERS (LSB=UPDATE, MSB=FRONT PANEL SCAN)
282E          132     AIOMF:  DS    1       ;A/D PEAK FLAG
282F          133     INDEX0: DS    2       ;TEMPORARY FOR TESTING PURPOSES
2831          134     AIODIF: DS    1       ;A/D INITIALIZATION FLAG (=1 AFTER INIALIZING)
2832          135     UFLAG:  DB    1       ;UPDATE DONE FLAG
2833          136     PSLNT:  DS    2       ;PEAK SAMPLE COUNTER
              137 ;
              138 ;  END OF RAM  2800-28FF
              139 ;
              140 ;
              141 ;*****************************************************************
              142 ;
              143 ;   CONTENTS OF RAM A800-A8FF
              144 ;
              145 ;
              146       ORG A800H
              147 ;
              148 ;
A800          149     BUFFER:DS     2       ;THE PEAK DATA BUFFER POINTER
              150 ;
              151 ;  VARIABLES AND FLAGS OF PEAKS, UPDATE, AND DISPLY SUBROUTINES THAT ARE
              152 ;  INITIALIZED TO ZERO BY SUBROUTINE INITAL
              153 ;
    A802      154 VBUFS   EQU     $
A802          155     CUTIME: DS    4       ;
A806          156     CRJ:    DS    4
A80A          157     CURSLP: DS    4       ;SLOPE OF CROSS CORRELATION AT ZERO DELAY
A80E          158     DCEXP:  DS    4
A812          159     DUX:    DS    4       ;VARIOUS DERIVATIVES OF X*Y
A816          160     DUYDY:  DS    4
A81A          161     DDY:    DS    4
A81E          162     DSEXP:  DS    4
A822          163     DX:     DS    4
A826          164     DXDX:   DS    4
A82A          165     DY:     DS    4
A82E          166     DYDY:   DS    4
A832          167     FMAX:   DS    4
A836          168     FREQ:   DS    4       ;CLOCK FREQUENCY
A83A          169     FREXP:  DS    4
A83E          170     FREZ:   DS    4
A842          171     GEJ:    DS    4
A846          172     INDEX1: DS    2       ;INDEX OF LOCATION IN XY ARRAY
A848          173     INDEX2: DS    2       ;INDEX OF LOCATION IN XY ARRAY
A84A          174     ISAMPL: DS    1       ;8 BIT INTEGER
A84B          175     JMAX:   DS    4       ;MAXIMUM, MINIMUM, AND PEAK VALUE OF INDEX IN
A84F          176     JMIN:   DS    4       ;  THE CROSS CORRELATION ARRAY
A853          177     JPEAK:  DS    4
```

```
AAA2                239     DUZUY1: DS   4
AAA6                240     DZ0X:   DS   4
AAAA                241     DZUY1:  DS   4
AAAE                242     UYUY1:  DS   4
AAB2                243     FULERF: DS   4
AAB6                244     PRTERR: DS   4
AABA                245     SLPRET: DS   4
AABE                246     TMETMT: DS   4
AAC2                247     XDERRF: DS   4
AAC6                248     XXI:    DS   4
AACA                249     YDLRET: DS   4
AACE                250     YDXI:   DS   4
AAD2                251     YYI:    DS   4
                    252 ;
                    253 ;
                    254 ;
                    255 ;   VARIABLES OF PROCESS, UPDATED AND DISPLAY THAT ARE INITIALIZED TO A
                    256 ;   NON-ZERO VALUE AT THE SUBROUTINE INITAL.
                    257 ;
AAD6 01             258     DCON:   DB      01H,00H,00H,00H         ;1
AAD7 80
AAD8 00
AAD9 00
AADA 01             259     DISCON: DB      01H,00H,00H,00H         ;1
AADB 80
AADC 00
AADD 00
AADE 01             260     FREQCN: DB      01H,00H,00H,00H         ;1
AADF 80
AAE0 00
AAE1 00
AAE2 01             261     DRATIO: DB      01H,00H,00H,00H         ;1
AAE3 80
AAE4 00
AAE5 00
AAE6 01             262     SKDR:   DB      01H,00H,00H,00H         ;1
AAE7 80
AAE8 00
AAE9 00
                    263 ;
      AAEA          264 VBUFE   EQU $
                    265 ;
                    266 ;   END OF RAM ABOVE AMPF
                    267 ;
                    268 ;*************************************************************
                    269 ;
                    270 ;
      0001          271     SIOL    EQU   SIOIN
      0001          272     SIOCI   EQU   SIOIN     ;CURRENT ADDRESSES FOR UARTS
                    273 ;
                    274 ;   END OF MASTER LIST OF EQUATES, GLOBAL VARIABLES AND RAM ASSIGNMENTS
                    275 ;.....................................................................
                    276 ;
                    277 ;
                    278 ;
                    279 ;*************************************************
                    280 ;
                    281 ;    MISC EQUATES TO GET THIS FROM ID ASSEMBLE
                    282 ;
                    283 ;*************************************************
```

```
A85e          179    MSKE:    DS     4
A85C          180    MIPI2:   DS     4
A86e          181    MI2:     DS     4        *MIPI2 AND TEMPORARY SYMBOL FOR DISPLY
Ae64          182    MIS:     DS     4        * CALCULATIONS
A86e          183    MIe:     DS     4
A86C          184    KMAX:    DS     4        *MAXIMUM, MINIMUM AND PEAK VALUE OF CROSS
Ae70          185    KMIN:    DS     4        * CORRELATION
A874          186    KPEAK:   DS     4
A87e          187    KXPNTR:  DS     2        *16 BIT INTEGER
A87A          188    KYPNTR:  DS     2        *16 BIT INTEGER
A87C          189    SCALE1:  DS     4        *SCALE1 ARE TEMPORARY STORAGE FOR UPDATE
A88e          190    SCALE2:  DS     4        * CALCULATIONS
A8e4          191    SNEW:    DS     4
A888          192    SNEXPT:  DS     4
A88C          193    SLOPE:   DS     4
A890          194    TEMPB:   DS     1       *TEMPORARY STORAGE USED BY DISPLY
A8e1          195    THETA:   DS     4
A8e2          19e    THETAL:  DS     4
A894          197    VALBLE:  DS     4
A89D          198    VALDAT:  DS     1
A89E          199    WASLOP:  DS     4
A8A2          200    X:       DS     4
A8Ae          201    XBAR:    DS     4
A8AA          202    XS:      DS     12       *THREE 4-BYTE LOCATIONS
A8Be          203    XX:      DS     4
A8BA          204    Y:       DS     4
A8BE          205    YBAR:    DS     4
A8C4          206    YBX:     DS     4
A8Ce          207    YS:      DS     12       *THREE 4-BYTE LOCATIONS
A8D2          208    YY:      DS     4
A8De          209    ZERO:    DS     4        *DOUBLEWORD FOR CONVERT AT DATA SAMPLE
A8DA          210    ZLSW:    DS     4        *VALUE OF ZERO FOR LAST AT DATA SAMPLE
              211 *
              212 *  FOLLOWING ARE ALSO INITIALIZED TO ZERO BUT MUST ALWAYS IMMEDIATELY BE KEPT
              213 *  IN THE RELATIVE ORDER THEY ARE HERE AS THEY ARE MOVED AS A BLOCK AT UPDATE
              214 *  TO A TEMPORARY STORAGE AREA.
              215 *
    A8De      216 UPBUF5   EQU  *
A8DE          217    KNEW:    DS     2000
A9Ae          218    DXDXN:   DS     4
A9AA          219    DXDXN:   DS     4
A9Ae          220    DXDYN:   DS     4
A9B2          221    DYDYN:   DS     4
A9Be          222    KCLEF1:  DS     4       *8 BIT INTEGER BUT USE 4 BYTES FOR CONVERSION TO FLOATING
A9BA          223    KTERM5:  DS     4       *8 BIT INTEGER BUT USE 4 BYTES FOR CONVERSION TO FLOATING
A9C2          224    SLOPEW:  DS     4
A9Ce          225    THETAW:  DS     4
A9Ce          226    XBARNEW: DS     4
A9CA          227    XBAR:    DS     4
A9CE          228    YBARNEW: DS     4
A9D2          229    YBAR:    DS     4
A9De          230    YYN:     DS     4
    A9DA      231 UPBUFE   EQU  *
              232 *
              233 *
              234 *  TEMPORARY STORAGE LOCATIONS FOR VARIABLES THAT ARE USED BY UPDATE. VARIABLES
              235 *  HERE MUST BE IN THE SAME ORDER AS IN UPBUF5-UPBUFE.
              236 *
    A9DA      237 INUF5    EQU  *
A9DA          238    ANEW:    DS   2000       *TEMPORARY STORAGE OF ANEW ARRAY
```

```
0008    59      ALSL    EQU   08H
0009    60      ALM     EQU   09H
000A    61      ALPP    EQU   0AH
000B    62      ALMK    EQU   0BH
0036    63      APF05   EQU   36H
0037    64      APF0B   EQU   37H
0017    65      APF0F   EQU   17H
0038    66      APUP5   EQU   38H
0018    67      APUPF   EQU   18H
001A    68      APUP1   EQU   1AH
A000    70      FPSW    EQU   0A000H  ;FRONT PANEL SWITCH ADDRESS
4800    71      FPLITE  EQU   4800H   ;FRONT PANEL LIGHT ADDRESS
0801    72      MAIMC   EQU   801H    ;AMPEX COMMAND/STATUS ADDRESS
0600    73      MATHU   EQU   600H    ;AMPEX DATA ADDRESS
1000    74      DATA    EQU   1000H   ;DATA FROM LOCATION
0000    75      RSTCNT  EQU   0000H
        76 ;
        77 ;*************************************************************************
        78 ;
        79 ;  BIOS RAM ASSIGNMENTS 7000-70FF
        80 ;
        81          ORG   7000H
7000    82 SERAD:   DS    1           ;TEMPORARY STORAGE USED BY MONITOR
7001    83 CSUM:    DS    1           ;CHECK SUM FOR PROMS
7002    84          DS    3
7005    85          DS    1           ;JUMP OPCODE FOR RST 6.5
7006    86 CLKVEC:  DS    2           ;RST 6.5 JUMP ADDRESS IS STORED HERE
7008    87          DS    7
700F    88 DUT:     DS    4           ;TEMPORARY STORAGE USED BY BCD DISPLAY ROUTINE: DISP
7013    89 TEMP:    DS    2           ;TEMPORARY STORAGE
        90 RSTADR   EQU   $           ;START OF RAM SUBROUTINE JMP TABLE
7015    91 START:   DS    3           ;JMP  3000H    (JMP INSTRUCTIONS ARE INITIALIZED
7018    92 INITAL:  DS    3           ;JMP  AINITA   IN RAM WHEN THE DIP SWITCHES ARE
7018    93 SCHED:   DS    3           ;JMP  ASCHED   READ)
701E    94 PROCES:  DS    3           ;JMP  APROCE
7021    95 UPDATE:  DS    3           ;JMP  AUPDAT
7024    96 DISPLY:  DS    3           ;JMP  ADISPL
7027    97 FLTRX:   DS    1           ;X FILTER SELECT WORD FOR MUX
7028    98 FLTRY:   DS    1           ;Y FILTER SELECT WORD FOR MUX
        99 ;
7100   100  STACK   EQU  7100H     ;REMAINDER OF THIS RAM IS USED FOR THE STACK
       101 ;
       102 ;  END OF BIOS RAM ASSIGNMENTS
       103 ;
       104 ;*************************************************************************
       105 ;
       106 ;    CONTENTS OF RAM 2800-28FF
       107 ;
       108 ;    THIS ENTIRE RAM IS INITIALIZED TO ZERO BY SUBROUTINE INITAL
       109 ;
       110      ORG 2800H
       111 ;
       112 ;   DATA ARRAYS
       113 ;
27FC   114   RX      EQU   $-4
2800   115          DS    2000
2BC4   116   RY      EQU   $-4         ;ARRAY PARAMETERS NOW WILL MATCH FORTRAN
2BC8   117          DS    400H
2A54   118   A       EQU   $-4
```

```
                1 ; STARTUP
                2 ; STARTUP, PROCESS, AND UPDATE
                3 ; 12/14/79
                4 ; CHANGES:
                5 ;   12/14 INITIAL EQUATE CHANGED
                6 ;   12/01 CONSTANT EQUATES CHANGED
                7 ;   11/23 REMOVED CONSTANTS
                8 ;   11/14 INITIAL REMOVED TO FIT PROGRAM INTO 2K
                9 ;   11/11/79  RECOVERED 11/10/79 FROM 1BF FILE. SOURCE SHOULD BE CHECKED
               10 ;   11/10 CROSS CORRELATION WORKS!
               11 ;   11/5  NEW GLOBAL LIST ADDED
               12 ;   11/1  CROSS CORRELATION REWRITTEN TO MATCH RADC FORTRAN
               13 ;   10/24 BCD DISPLAY CONSTANTS AND YS11 MOVED TO MONITOR
               14 ;   10/17 VARIABLE BLOCK MODIFIED TO INCLUDE UPDATE VARIABLES
               15 ;   10/15 ADDED PROCESS
               16 ;   10/13 ADDED MSTAT, MISC CHANGES TO MASTER VARIABLE BLOCK
               17 ;   10/07 SUBROUTINE JUMP TABLE RELOCATED .O BEGIN AT 7014H
               18 ;         OUT MOVED TO 7010 (USES 4 BYTES)
               19 ;
               20 ;
               21 ;*************************************************  ** ************ ************
               22 ;
               23 ;  MASTER LIST OF GLOBAL VARIABLES, AND ASSIGNMENTS, E.G. INCLUDE A COPY
               24 ;  OF THIS IN DEVELOPING A SUBROUTINE TO BE INCLUDED IN THE SYSTEM.
               25 ;
               26 ;
0000C          27      ASADD   EQU   0CH
0000D          28      ASSUB   EQU   0DH
0000E          29      ASMUL   EQU   0EH
0000F          30      ASNEG   EQU   7FH
00010          31      ASDIV   EQU   0FH
0002C          32      ADADD   EQU   2CH
0002D          33      ADSUB   EQU   2DH
0002E          34      ADMUL   EQU   2EH
00036          35      ADNEG   EQU   36H
0002F          36      ADDIV   EQU   2FH
00010          37      AFADD   EQU   10H
00011          38      AFSUB   EQU   11H
00012          39      AFMUL   EQU   12H
00013          40      AFDIV   EQU   13H
0001F          41      AFIXS   EQU   1FH
0001E          42      AFIXD   EQU   1EH
0001D          43      AFLTS   EQU   1DH
0001C          44      AFLTD   EQU   1CH
00034          45      AXMSS   EQU   34H
00035          46      AXMSD   EQU   35H
00037          47      AXDMS   EQU   37H
00039          48      AXDMD   EQU   39H
0001A          49      AXCMP   EQU   1AH
00001          50      AEXPF   EQU   01H
00002          51      ASIN    EQU   02H
00003          52      ACOS    EQU   03H
00000          53      ATAN    EQU   00H
00004          54      AFXP    EQU   04H
00005          55      AASIN   EQU   05H
00006          56      AACOS   EQU   06H
00007          57      AATAN   EQU   07H
```

```
                        284     CR      EQU  0DH
                        285     LF      EQU  0AH
                        286     ERNO    EQU  1E5DH
                        287     MODE    EQU  0C5EH        ;MODE FOR SIO
                        288     ERRSUB  EQU  1E39H            ;ERROR OUTPUT ROUTINE
                        289     BEGIN   EQU  1E43H            ;BEGINNING OF MONITOR
                        290     USER    EQU  1A0FH            ;RUNNABLE USER
                        291     RESTART EQU  1EE9H
                        292     FADD2   EQU  1F62H
                        293     FADD1   EQU  1F67H
                        294     FADD    EQU  1F6AH
                        295     FSUB2   EQU  1F70H
                        296     FSUB1   EQU  1F78H
                        297     FSUB    EQU  1F7BH
                        298     FMUL2   EQU  1F81H          ;ARITHMETIC SUBROUTINES
                        299     FMUL1   EQU  1F86H
                        300     FMUL    EQU  1F89H
                        301     FDIV2   EQU  1F8FH
                        302     FDIV1   EQU  1F94H
                        303     FDIV    EQU  1F97H
                        304     FLOAT   EQU  1F9DH
                        305     FLOAT0  EQU  1FA7H
                        306     FLSH4   EQU  1FADH
                        307     POP4    EQU  1FC4H
                        308     MSTAT   EQU  1FF7H        ;GET STATUS OF MPSIO
                        309     SRUN    EQU  07H          ;
                        310     MINIT   EQU  1800H        ;HARDWARE INIT.
                        311     TIMER   EQU  1CF5H
                        312 ;
                        313 ;
                        314 ;   FOR THE JUMP VECTOR TABLE
                        315 ;
                        316     AINITA  EQU  925DH            ;ACTUAL ADDRESS OF INITIAL
                        317 ;   AMODE   EQU  0                ;ACTUAL ADDRESS OF MODES
                        318     ASTART  EQU  9039H            ;ACTUAL ADDRESS OF START
                        319     ASCHED  EQU  908DH            ;ACTUAL ADDRESS OF SCHED
                        320 ;   AUPDAT  EQU  0                ;ACTUAL ADDRESS OF UPDATE
                        321     ADISPL  EQU  94A1H            ;ACTUAL ADDRESS OF DISPLY
                        322 ;
                        323     ONE     EQU  9000H              ;FLOATING POINT CONSTANTS
                        324     FWO     EQU  9004H
                        325     FEN     EQU  9008H
                        326     ONEH    EQU  900CH
                        327 ;
                        328     CODONS  EQU  9018H
                        329     MXDLE   EQU  901AH
                        330     MXDSE   EQU  901DH
                        331     MXFRE   EQU  9021H
                        332     MXSKE   EQU  9025H
                        333     SMPLPR  EQU  9029H            ;ALGORITHM CONSTANTS
                        334     INTRVL  EQU  902DH
                        335     TWOPI   EQU  9031H
                        336     UPTIME  EQU  SMPLPR
                        337     ZSUMIN  EQU  9035H
                        338 ;   SET UP THE INTERRUPT VECTORS
                        339 ;
                        340 ;
                        341         ORG 0000H         ;START THIS PROGRAM AT THE TOP
0000 F3                 342         DI                ;DISABLE INTERRUPTS UNTIL THEY ARE SET UP
0001 31 0071            343         LXI  SP,STACK     ;SET UP THE STACK POINTER
```

```
0004 C3 3F00 344            JMP   INITT
                 345            ORG   0008H
0008 C3 E91A 346            JMP   RESTART       ;RST 1
                 347            ORG   0010H
0010 1E 32   348            MVI   E,'2'
0012 C3 2516 349            JMP   ERRO          ;RST 2
                 350            ORG   0018H
0018 1E 33   351            MVI   E,'3'
001A C3 2518 352            JMP   ERRO          ;RST 3
                 353            ORG   0020H
0020 1E 34   354            MVI   E,'4'
0022 C3 2518 355            JMP   ERRO          ;RST 4
                 356            ORG   0027H
0027 1E 35   357            MVI   E,'5'
0029 C3 2516 358            JMP   ERRO          ;RST 5
002C C3 1070 359            JMP   7010H         ;RST 5.5
                 360            ORG   002FH
002F 1E 36   361            MVI   E,'6'
0031 C3 2518 362            JMP   ERRO
0034 C3 0570 363            JMP   7005H         ;RST 6.5  INTERRUPT VECTOR
                 364            ORG   0037H
0037 1E 37   365            MVI   E,'7'
0039 C3 2516 366            JMP   ERRO
003C C3 0070 367            JMP   7000H         ;RST  7.5 INTERRUPT VECTOR
003F 3E 0F   368 INITT:     MVI   A,0FH         ;TURN OFF ALL INTERRUPTS
0041 30      369            SIM                 ;SET MASK
0042 21 0570 370            LXI   H,7005H       ;RST 6.5 JUMP VECTOR
0045 36 C3   371            MVI   M,0C3H        ;UNCONDITIONAL JUMP
0047 21 E800 372            LXI   H,RESTART     ;WHERE TO JUMP TO
004A 22 0670 373            SHLD  CLAVEC        ;STORE IT IN THE JUMP VECTOR
                 374 ;
                 375 ;
                 376 ;          TIMER INITIALIZATION  (8253)
                 377 ;
004D 3E D0   378            MVI   A,0D0H        ;SET TIMER #3 UP
004F D3 7B   379            OUT   7BH           ;INTERRUPT MODE
0051 3E 7B   380            MVI   A,7BH
0053 D3 7A   381            OUT   7AH
0055 3E 27   382            MVI   H,27H
0057 D3 7A   383            OUT   7AH
0059 FB      384            EI
                 385 ;
                 386 ;          INITIALIZE THE BIOS
                 387 ;
005A 3E 01   388            MVI   A,01H
005C D3 70   389            OUT   70H
005E 3E 04   390            MVI   A,04H
0060 D3 71   391            OUT   71H
0062 3E 00   392            MVI   A,00H
0064 D3 71   393            OUT   71H
                 394 ;
                 395 ;*************************************************
                 396 ;
                 397 ;          PROGRAM TO READ THE DIP SWITCHES
                 398 ;
                 399 ;*************************************************
0066 3E 00   400 DIPRD:     MVI   A,00H
0068 D3 70   401            OUT   70H
006A DB 73   402            IN    73H           ;GET THE SWITCH POSITIONS
006C 47      403            MOV   B,A           ;AND SAVE A COPY
```

```
00A0 CA 1570  404          JZ   START
00A3 21 A407  405 ;FAR:    LXI  H,FJTABS       ;FROM JUMP TABLE START
00A6 11 1570  406          LXI  D,RJTABS       ;FROM JUMP TABLE START
00A9 0E 12    407          MVI  C,FJTABE-FJTABS
00AB 7E       408 LL:      MOV  A,M
00AC 12       409          STAX D              ;TRANSFER BYTE
00AD 23       410          INX  H              ;INCREMENT POINTERS
00AE 13       411          INX  D
00AF 0D       412          DCR  C              ;BLOCKLENGTH COUNTER
00B0 C2 A400  413          JNZ  LL
00B3 7E       414          MOV  A,M
00B4 E6 10    415          ANI  10H
00B6 C2 A400  416          JNZ  TEST2
00B9 CD 0018  417          CALL HINIT
00BC CD 4510  418          CALL TIMER
00BF CD 0F1A  419          CALL JBLK
00C2 C3 A100  420 NULL:    JMP  NULL           ;END WAIT FOR OPERATOR TO CONTINUE
              421 ;
00C5 78       422 TEST2:   MOV  A,B
00C6 E6 08    423          ANI  08H
00C8 C2 1570  424          JNZ  START
00CB 21 4518  425          LXI  H,BEGIN
00CE 22 1670  426          SHLD START+1
00D1 C3 1570  427          JMP  START
              428 ;
              429 ;**********************************
              430 ;
              431 ;     PRODES SUBROUTINE
              432 ;
              433 ;**********************************
              434 ;
00D4 2A 0EAB  435 PROBLE:  LHLD XS+4
00D7 22 EAAB  436          SHLD XS+8
00DA 2A F0AB  437          LHLD YS+6
00DD 22 E4AB  438          SHLD XS+10D         ;XS(3) = XS(2)
00E0 2A EAAB  439          LHLD YS+4
00E3 22 EEAB  440          SHLD YS+8
00E6 2A CCAB  441          LHLD YS+6
00E9 22 DOAB  442          SHLD YS+10D         ;YS(3) = YS(2)
00EC 2A AAAB  443          LHLD XS
00EF 22 AEAB  444          SHLD XS+4
00F2 2A ACAB  445          LHLD XS+2
00F5 22 B0AB  446          SHLD XS+6           ;XS(2) = XS(1)
00F8 2A C8AB  447          LHLD YS
00FB 22 CAAB  448          SHLD YS+4
00FE 2A CAAB  449          LHLD YS+2
0101 22 CCAB  450          SHLD YS+6           ;YS(2) = YS(1)
0104 21 A07B  451          LXI  H,XDC
0107 11 A2AB  452          LXI  D,Z
010A CD 701F  453          CALL FSUB2          ;Z = XDC
010D 21 AAAB  454          LXI  H,XS
0110 CD C41F  455          CALL FDF4
0113 21 B6AB  456          LXI  H,YDC
0116 11 A4AB  457          LXI  D,Y
0119 CD 701F  458          CALL FSUB2          ;Y = YDC
011C 21 E2AA  459          LXI  H,DELTIU       ;DELTAMATIU
011F CD 661F  460          CALL FMUL1
0122 21 C8AB  461          LXI  H,YS           ;YS(1) = (Y-YDC)*DELTAMATIU
```

```
00F4 CD C41F 464            CALL   FDF4
00F7 21 ACAC 465            LXI    H,XS+4
00FA 11 ACA8 466            LXI    D,XS+4
00FD CD 811F 467            CALL   FMUL2        ; XS(2) SQUARED
0100 21 CAA8 468            LXI    H,YS+4
0103 11 CAA8 469            LXI    D,YS+4
0106 CD 811F 470            CALL   FMUL2        ; YS(2) SQUARED
0109 CD CA1F 471            CALL   FADD         ; XS(2) * XS(2)  +  YS(2) * YS(2)
010C 3E 17   472            MVI    A,TEMPTOF    ;SAVE IT ON THE INTERNAL STACK FOR FUTURE USE
010E 32 0106 473            STA    MATHC
0111 21 B6A8 474            LXI    H,ZSQ        ;PUT ONE CONV INTO ZSQ
0114 CD C41F 475            CALL   FDF4
0117 21 B590 476            LXI    H,ZSQMIN
011A CD 781F 477            CALL   FSUB1        ;ZSQ - ZSQMIN  IF  NO OVER ZSQ .LE. ZSQMIN
011D CD F71F 478            CALL   MSTAT        ;CHECK THE STATUS WORD
0120 E6 60   479            ANI    60H          ;MASK OUT ALL BITS BUT SIGN AND ZERO
0122 CA 2901 480            JZ     CALC6
0125 AF      481 CALC5:     XRA    A            ;ZERO THE CALCULATION
0126 32 C7A8 482            STA    MINSIG       ;IF(ZSQ .LE. ZSQMIN)MINSIG=0
0129 3A C7A8 483 CALC6:     LDA    MINSIG
012C FE 00   484            CPI    00H
012E C2 3E01 485            JNZ    L220         ;IF(MINSIG .NE. 0)GO TO 220
0131 AF      486            XRA    A
0132 32 99A8 487            STA    VALIDC       ;VALIDC = 0
0135 32 9BA8 488            STA    VALIDXY      ;VALIDXY = 0
0138 32 AAA8 489            STA    ISAMPLE      ;ISAMPLE = 0
013B C3 1A04 490            JMP    L230         ;GO TO 230
013E 3A 9DA8 491 L220:      LDA    VALIDXY      ;LABEL 220 IN FORTRAN VERSION
0141 FE 03   492            CPI    03H
0143 D2 4A01 493            JP     D2           ;IF(VALIDXY .P. 3)GO TO D2
0146 3C      494            INR    A
0147 32 9DA8 495            STA    VALIDXY      ;VALIDXY = VALIDXY + 1
014A FE 03   496 D2:        CPI    03H
014C FA 1A04 497            JM     L230         ;IF(VALIDXY .LT. 3)GO TO 230
             498 ;
             499 ;  CALCULATE THE DERIVATIVES
             500 ;
014F 11 AAA8 501            LXI    D,XS         ;CALCULATE THE DERIVATIVES
0152 21 ACA8 502            LXI    H,XS+2
0155 CD 701F 503            CALL   FSUB2        ;XS(1) - XS(3)
0158 21 0490 504            LXI    H,TWO        ;MAINFEST CONSTANT TWO FOR 32 BITS
015B CD 941F 505            CALL   FDIV1
015E 21 CCA8 506            LXI    H,DX         ;DX = (XS(1) - XS(3))/2
0161 CD C41F 507            CALL   FDF4
0164 11 CEA8 508            LXI    D,YS
0167 21 CEA6 509            LXI    H,YS+2
016A CD 701F 510            CALL   FSUB2        ;YS(1)  - YS(3)
016D 21 0490 511            LXI    H,TWO
0170 CD 941F 512            CALL   FDIV1
0173 21 CAA8 513            LXI    H,DY         ;DY = (YS(1) - YS(3))/2
0176 CD C41F 514            CALL   FDF4
0179 21 CAA8 515            LXI    H,DY
017C 11 ACA8 516            LXI    D,XS+2
017F CD 811F 517            CALL   FMUL2        ;DY * XS(3)
0182 21 CCA8 518            LXI    H,DX
0185 11 CEA8 519            LXI    D,YS+2
0188 CD 811F 520            CALL   FMUL2        ;DX * YS(3)
018B CD 781F 521            CALL   FSUB
018E 21 B6A8 522            LXI    H,ZSQ
0191 CD 941F 523            CALL   FDIV1        ;FINALLY, THE INCMO
```

```
0194 3E 1F    524          MVI   A,#1FH    ;FLUSH W BUFF
0196 32 01CE  525          STA   MATHC
0199 21 95AE  526          LXI   H,THETACHG  ;THETACHG(0) = 0 & (S(3) - 0) & (S(3)/Z)<0
019C CD C41F  527          CALL  FCP4
019F 3A 01CE  528          LDA   MATHC       ;TAKE THE ABSOLUTE VALUE
01A2 E6 40    529          ANI   40H
01A4 CA ACD1  530          JZ    OKAY
01A7 3E 1F    531          MVI   A,#1FH
01A9 32 01CE  532          STA   MATHC
01AC 21 CD9C  533  OKAY:   LXI   H,THETAL
01AF CD 781F  534          CALL  FSUB1       ;ABS(THETACHG) - THETALIM
01B2 CD F71F  535          CALL  MSTAT       ;CHECK THE STATUS WORD
01B5 E6 80    536          ANI   80H
01B7 C2 C701  537          JNZ   L220        ;IF ABS(THETACHG) <= THETALIM GO TO 220
01BA AF       538          XRA   A
01BB 32 99A8  539          STA   VALIDCC     ;VALIDCC = 0
01BE 32 9DA8  540          STA   VALIDXY     ;VALIDXY = 0
01C1 32 9AA8  541          STA   ISAMPL      ;ISAMPL = 0
01C4 C3 1A04  542          JMP   L230        ;GO TO 230
              543 ;
              544 ;  ACCEPT THIS SAMPLE
              545 ;
01C7 3A 96A9  546  L220:   LDA   NACEPT
01CA 3C       547          INR   A
01CB 32 96A9  548          STA   NACEPT      ;NACEPT = NACEPT + 1
01CE 21 C0A9  549          LXI   H,XUCNEW
01D1 11 ACA8  550          LXI   D,X
01D4 CD 621F  551          CALL  FADD2
01D7 21 C0A9  552          LXI   H,XUCNEW    ;XUCNEW = XUCNEW + X
01DA CD C41F  553          CALL  FCP4
01DD 21 CEA9  554          LXI   H,YUCNEW
01E0 11 B0A8  555          LXI   D,Y
01E3 CD 621F  556          CALL  FADD2
01E6 21 CEA9  557          LXI   H,YUCNEW    ;YUCNEW = YUCNEW + Y
01E9 CD C41F  558          CALL  FCP4
01EC 21 ACA8  559          LXI   H,XS+4
01EF 11 ACA8  560          LXI   D,XS+4
01F2 CD B11F  561          CALL  FMUL2
01F5 21 CAA9  562          LXI   H,XXN
01F8 CD 671F  563          CALL  FADD1
01FB 21 CAA9  564          LXI   H,XXN       ;XXN = XXN + XS(2) * XS(2)
01FE CD C41F  565          CALL  FCP4
0201 21 C0A8  566          LXI   H,YS+4
0204 11 C0A8  567          LXI   D,YS+4
0207 CD B11F  568          CALL  FMUL2
020A 21 D0A9  569          LXI   H,YYN
020D CD 671F  570          CALL  FADD1
0210 21 D0A9  571          LXI   H,YYN       ;YYN = YYN + YS(2) * YS(2)
0213 CD C41F  572          CALL  FCP4
0216 21 D0A7  573          LXI   H,THETAN
0219 11 D5A8  574          LXI   D,THETAL
021C CD 621F  575          CALL  FADD2
021F 21 D0A7  576          LXI   H,THETAN    ;THETAN = THETAN + THETAL
0222 CD C41F  577          CALL  FCP4
              578          ;
              579          ;CROSS CORRELATION
              580          ;
              581          ;
0225 3A C728  582          LDA   LCROSSA
0228 FE 00    583          CPI   00H         ;SET THE CONDITION CODES
```

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023A CA 5B02 554          JZ    LL24          ;IF(+NOT. CROSSING)GO TO 24
023D 3A 4AA6 555          LDA   ISAMPL
0240 3C      556          INR   A
0241 32 4AA6 557          STA   ISAMPL        ;ISAMPL = ISAMPL + 1
0244 21 1B7D 558          LXI   H,LL0WNS
0247 96      559          SUB   M
0248 C2 5B02 560          JNZ   LL24          ;IF(ISAMPL .NE. LOWNS/60) TO 24
024B AF      561          XRA   A
024C 32 4AA6 562          STA   ISAMPL        ;ISAMPL = 0
024F 2A 7E9B 563          LHLD  NXPNTR
0252 2B      564          DCX   H
0253 7C      565          MOV   A,H
0254 E6 80   566          ANI   80H
0256 CA 4F02 567          JZ    LL1           ;IF((NXPNTR-1) .LT. 0)NXPNTR = 50
0259 21 0800 568          LXI   H,2000
025C 22 7B9B 569          SHLD  NXPNTR
025F 11 ACA6 600 LL1:     LXI   D,X
0262 21 A6A6 601          LXI   H,XBUF
0265 CD 701F 602          CALL  FSUB2
0268 2A 7B9B 603          LHLD  NXPNTR
026B EB      604          XCHG
026C 21 FD27 605          LXI   H,NX
026F 1A      606          LDAX  D
0270 CD C41F 607          CALL  FDF4          ;NX=NXPNTR/ - X-XBUF
0273 1B      608          DCX   D
0274 1B      609          DCX   D
0275 1B      610          DCX   D
0276 1B      611          DCX   D
0277 EB      612          XCHG
0278 22 7B9B 613          SHLD  NXPNTR        ;NXPNTR = NXPNTR - 4
027B 2A 7AA6 614          LHLD  NYPNTR
027E 2B      615          DCX   H
027F 7C      616          MOV   A,H
0280 E6 80   617          ANI   80H
0282 CA 8702 618          JZ    LL2
0285 21 9001 619          LXI   H,4000
0288 22 7AA6 620          SHLD  NYPNTR        ;IF(NYPNTR .LE. 0)NYPNTR = 100
028B 11 BAA6 621 LL2:     LXI   D,Y
028E 21 EEA6 622          LXI   H,YBUF
0291 CD 701F 623          CALL  FSUB2
0294 2A 7AA6 624          LHLD  NYPNTR
0297 EB      625          XCHG
0298 21 D41F 626          LXI   H,NY
029B 1A      627          LDAX  D
029C CD C41F 628          CALL  FDF4          ;NY(NYPNTR/ - Y-YBUF
029F 1B      629          DCX   D
02A0 1B      630          DCX   D
02A1 1B      631          DCX   D
02A2 1B      632          DCX   D
02A3 EB      633          XCHG
02A4 22 7AA6 634          SHLD  NYPNTR        ;NYPNTR = NYPNTR - 1
02A7 3A 99A6 635          LDA   VALUCL
02AA FE 64   636          CPI   100D
02AC D2 B302 637          JP    LL3
02AF 3C      638          INR   A
02B0 32 99A6 639          STA   VALUCL        ;IF(VALUCL .LT. 100)VALUCL = VALUCL + 1
02B3 FE 64   640 LL3:     CPI   100D
02B5 DA 5F03 641          JC    LL30          ;IF(VALUCL .LT. 100) GO TO 30
02B8 2A BAA6 642          LHLD  NTEMPS
02BB 23      643          INX   H
```

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                                        SHLD  * FRMS          ;FILEMS = FFRMS + 1
                                        LHLD  FFRMS           ;HL = FFRMS = INDEX1
                                        MOV   A,M
                                        ANI   80H
                                        JNZ   CL4             ;IF (INDEX1 < 0) INDEX1 = 50
                                        INR   M
                                        JNZ   CL5
                                        MOV   A,L
                                        ORI   00H
                                        JZ    CL5             ;IF (INDEX1 = 0) INDEX1 = 50
02D2 21 2600  654 CL4:                  LXI   H,2600
02D5 EB       655 CL5:                  XCHG                  ;D-E = INDEX1
02D6 21 FC27  656                       LXI   H,KX
02D9 19       657                       DAD   D
02DA CD A81F  658                       CALL  PUSH4
02DD 21 303E  659                       LXI   H,KX50
02E0 CD C41F  660                       CALL  PGP4            ;KX50 = KX(INDEX1)
02E3 01 0200  661                       LXI   B,0002H       ;B-C IS COUNTER
02E6 2A 7AA8  662 L223:                 LHLD  KYFNIK
02E9 11 CC00  663                       LXI   D,204D
02EC 19       664                       DAD   D
02ED 79       665                       MOV   A,C
02EE 3F       666                       CMA
02EF 3C       667                       INR   A
02F0 4F       668                       MOV   C,A
02F1 06 FF    669                       MVI   B,0FFH
02F3 09       670                       DAD   B             ;H-L  = KYFNIK + 51 -J
02F4 09       671                       DAD   B
02F5 09       672                       DAD   B
02F6 09       673                       DAD   B
02F7 22 48A8  674                       SHLD  INDEX1
02FA 79       675                       MOV   A,C
02FB 2F       676                       CMA
02FC 3C       677                       INR   A
02FD 4F       678                       MOV   C,A
02FE 06 00    679                       MVI   B,00H
0300 11 70FE  680                       LXI   D,-400D
0303 19       681                       DAD   D
              682 ;
              683 ;       IF H-L (WHICH IS INDEX1) >0 SHLD INDEX1 ELSE SKIP
              684 ;
0304 7C       685                       MOV   A,H
0305 E6 80    686                       ANI   80H
0307 C2 0703  687                       JNZ   CL7           ;SIGN BIT SET = <0 => SKIP
030A B4       688                       ORA   H
030B C2 0903  689                       JNZ   CL6           ;IF NOT ZERO DON'T BOTHER TO TEST L
030E 7D       690                       MOV   A,L
030F F6 00    691                       ORI   00H
0311 CA 0703  692                       JZ    CL7
0314 22 48A8  693 CL6:                  SHLD  INDEX1
0317 11 C400  694 CL7:                  LXI   D,196D
031A 2A 7AA8  695                       LHLD  KYFNIK
031D 19       696                       DAD   D
031E 09       697                       DAD   B
031F 09       698                       DAD   B
0320 09       699                       DAD   B
0321 09       700                       DAD   B
0322 22 48AB  701                       SHLD  INDEX2        ;INDEX2 = KYFNIK + 49 * J
0325 11 70FE  702                       LXI   D,-400D
0328 19       703                       DAD   D             ;INDEX2 -=400
```

```
0319 7C       704          MOV  A,H
031A E6 80    705          ANI  80H
031C C2 2003  706          JNZ  LC9
031F B4       707          ORA  H
0320 C2 2903  708          JNZ  LC8
0323 7D       709          MOV  A,L
0324 FE 00    710          CPI  00H
0326 CA 2D03  711          JZ   LC9
0329 2A 4BAB  712 LC8:     SHLD INDEX2        ;IF((INDEX2 -100) .GT. 0)INDEX2 = INDEX2 -100
032C 2A 4BAB  713 LC9:     LHLD INDEX1
032F 11 0428  714          LXI  D,04
0332 19       715          DAD  D
0333 CD AD1F  716          CALL PUSH4
0336 2A 4BAB  717          LHLD INDEX2
0339 11 0426  718          LXI  D,04
033C 19       719          DAD  D
033D CD 781F  720          CALL FSUB1
0340 21 202B  721          LXI  H,RX30
0343 CD 6E1F  722          CALL FMUL1
0346 21 0EAB  723          LXI  H,RNEW
0349 09       724          DAD  B
034A 09       725          DAD  B
034B 09       726          DAD  B
034C 09       727          DAD  B             ;H=L FR> RNEW(J)
034D CD 671F  728          CALL FADD1
0350 CD C41F  729          CALL PUT4
0353 03       730          INX  B
0354 79       731          MOV  A,C
0355 FE 35    732          CPI  35
0357 DA 0B03  733          JC   LL3
035A C9       734          RET
              735 ;
              736 ;
              737 ;        SLOPE
              738 ;
              739 ;
035B AF       740 LL24:    XRA  A
035C 21 2B2B  741          LXI  H,SLOPEA
035F 86       742          ADD  M
0360 CA 7B03  743          JZ   CSNEW         ;IF(SLOPEA) SLPNEW = SLPNEW + DX#YS(2)
0363 21 2CAB  744          LXI  H,DX
0366 11 CAAB  745          LXI  D,YS+4
0369 CD 611F  746          CALL FMUL2
036C 21 0EA9  747          LXI  H,SLPNEW
036F CD 671F  748          CALL FADD1
0372 21 0EA9  749          LXI  H,SLPNEW
0375 CD C41F  750          CALL PUT4
              751 ;
              752 ;  CALCULATE STEP PARAMETERS
              753 ;
0378 AF       754 CSNEW:   XRA  A
0379 21 C92B  755          LXI  H,STEPWA
037C 86       756          ADD  M
037D CA F803  757          JZ   LL28          ;IF(.NOT. STEPWA)GO TO 220
0380 21 AAAB  758          LXI  H,YS
0383 CD AD1F  759          CALL PUSH4
0386 21 0470  760          LXI  H,TWO
0389 11 0EAB  761          LXI  D,XS+4
038C CD 811F  762          CALL FMUL2
038F CD 781F  763          CALL FSUB
```

```
0392 21 2AA8 784          LXI  H,XSAVE
0395 CD 0 1F 785          CALL FADD1
0398 21 12A8 786          LXI  H,DDX          ;DDX=XSAVE-X = SAVE(2) - X(2)
039B CD C41F 787          CALL PUP4
039E 21 0EA8 788          LXI  H,YS
03A1 CD 0D1F 789          CALL PUSH4
03A4 21 04F0 790          LXI  H,ONE
03A7 11 AEA8 791          LXI  D,AS+4
03AA CD 811F 792          CALL FMUL2
03AD CD 781F 793          CALL FSUB
03B0 21 0EA8 794          LXI  H,YS+6
03B3 CD 671F 795          CALL FADD1
03B6 21 1AA8 796          LXI  H,DET          ;DET=YS(3) - SAVE(3) + YS(3)
03B9 CD C41F 797          CALL PUP4
03BC 21 12A8 798          LXI  H,DDX
03BF 11 2AA8 799          LXI  D,DT
03C2 CD 811F 800          CALL FMUL2
03C5 21 A6A9 801          LXI H,DDXDTN
03C8 CD 671F 802          CALL FADD1
03CB 21 A6A9 803          LXI  H,DDXDTN       ;DDXDTN = DDXDTN + DDX * DT
03CE CD C41F 804          CALL PUP4
03D1 21 22A8 805          LXI  H,DX
03D4 11 32A8 806          LXI  D,DT
03D7 CD 811F 807          CALL FMUL2
03DA 21 AAA9 808          LXI  H,DTDXDN
03DD CD 671F 809          CALL FADD1
03E0 21 AAA9 810          LXI  H,DTDXDN       ;DTDXDN = DTDXDN + DADDA
03E3 CD C41F 811          CALL PUP4
03E6 21 2AA8 812          LXI  H,DY
03E9 11 3AA8 813          LXI  D,DT
03EC CD 811F 814          CALL FMUL2
03EF 21 82A9 815          LXI  H,DTDTDN
03F2 CD 671F 816          CALL FADD1
03F5 21 82A9 817          LXI  H,DTDTDN       ;DTDTDN = DTDTDN + DTSDT
03F8 CD C41F 818          CALL PUP4
03FB 3A 262B 819  L228.   LDA  SLOPEA
03FE 21 2928 820          LXI  H,SKEWA
0401 BE      821          CMP  M
0402 CA 1A04 822          JZ   L230           ;IF(.NOT. (SLOPEA .GE. SKEWA)) TO 230
0405 21 AAA8 823          LXI  H,YS+4
0408 11 22A8 824          LXI  D,DX
040B CD 811F 825          CALL FMUL2
040E 21 D2A9 826          LXI  H,YDXN
0411 CD 671F 827          CALL FADD1
0414 21 D2A9 828          LXI  H,YDXN         ;YDXN = YDXN + YS(2)*DDX
0417 CD C41F 829          CALL POP4
041A 2A D6A8 830  L230:   LHLD ZSU
041D 22 D0A8 831          SHLD ZLSU           ;ZLSU = ZSU
0420 2A D8A8 832          LHLD  ZSUM2
0423 22 DCA8 833          SHLD  ZLSUM2
0426 11 D0A8 834          LXI  D,ZLSU         ;IF(ZLSU.LE.ZSUMIN) MINSIGN1
0429 21 3590 835          LXI  H,ZSUMIN
042C CD F01F 836          CALL  FSUB2
042F CD F71F 837          CALL MSTAT
0432 E6 40   838          ANI  40H
0434 C6      839          RZ                  ;ZLSU   ZSUMIN =  SIGN NOT SET
0435 3E 01   840          MVI  A,01H
0437 32 D7A8 841          STA  MINSIG
043A C9      842          RET
             843 ;*******************************************************
```

```
                        824 ;
                        825 ;           UPDATE DATA FOR THE DISPLAY
                        826 ;
                        827 ;*****************************************
                        828 ;
                        829 ;
                        830 ;MOVE NEW DATA TO LOCAL VARIABLES IN UPDATE
                        831 ;CLEAR THE NEW DATA VARIABLES TO ZERO
                        832 ;
     043E               833 AUPDAT  EQU   $
043E 3A 8844            834         LDA   NACEPT
0441 F6 00              835         ORI   00H           ;IF(NACEPT .EQ. 0) GO TO L200
0443 CA 8207            836         JZ    L200
0446 21 0EA8            837         LXI   H,UPBUFS      ;H-L POINTS TO SOURCE LOCATION
0449 11 89AA            838         LXI   D,TBUFS       ;D-E POINTS TO TEMPORARY LOCATION
044C 06 FC              839         MVI   B,UPBUFE-UPBUFS ;COUNT NUMBER OF BYTES TO MOVE IN B
044E 7E                 840 UPDAT1: MOV   A,M
044F EB                 841         XCHG
0450 77                 842         MOV   M,A
0451 EB                 843         XCHG
0452 AF                 844         XRA   A             ;CLEAR ACC
0453 77                 845         MOV   M,A           ;CLEAR UPBUF VARIABLE
0454 23                 846         INX   H
0455 13                 847         INX   D
0456 05                 848         DCR   B
0457 C2 4E04            849         JNZ   UPDAT1
045A 32 2C1B            850         STA   UFLAG
045D 21 2CAA            851         LXI   H,FACEPT
0460 CD 7D1F            852         CALL  FLOAT
0463 CD C41F            853         CALL  POP4
                        854 ;
0466 11 0EA8            855         LXI   D,DCEXPT      ;IF(DCEXPT .LT. MXDCE)DCEXPT = DCEXPT + 1
0469 21 1990            856         LXI   H,MXDCE
046C CD 701F            857         CALL  FSUB
046F CD F71F            858         CALL  MSTAT
0472 E6 40              859         ANI   40H
0474 CA E304            860         JZ    U1
0477 11 0090            861         LXI   D,ONE
047A 21 0EA8            862         LXI   H,DCEXPT
047D CD 621F            863         CALL  FADD
0480 21 0EA8            864         LXI   H,DCEXPT
0483 CD C41F            865         CALL  POP4
                        866 ;
0486 11 0EA8            867 U1:     LXI   D,DCEXPT      ;IF(DCEXPT.GE.(DC2M+DC2M)/DC2M+DC2M+DC2M
0489 21 0E9A            868         LXI   H,DC2M
048C CD 701F            869         CALL  FSUB
048F 21 0E9A            870         LXI   H,DC2M
0492 CD 781F            871         CALL  FSUB
0495 CD F71F            872         CALL  MSTAT
0498 E6 40              873         ANI   40H
049A C2 A304            874         JNZ   U2
049D 11 0E9A            875         LXI   D,DC2M
04A0 21 0E9A            876         LXI   H,DC2M
04A3 CD 621F            877         CALL  FADD
04A6 21 0E9A            878         LXI   H,DC2M
04A9 CD C41F            879         CALL  POP4
                        880 ;
04AC 11 2C1A            881 U2:     LXI   D,XX1         ;XX=XX+(XX1/FACEPT-XX1/DC2M
04AF 21 2CAA            882         LXI   H,FACEPT
04B2 CD 5F1F            883         CALL  FDIV2
```

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                        ;
04F5 21 B5AA 854        LXI  H,YY
04F8 CD 941F 855        CALL FSUB1
04FB 21 B5AA 856        LXI  H,DU2M
04FE CD 941F 857        CALL FDIV1
0501 21 B5AE 858        LXI  H,XX
0504 CD 671F 859        CALL FADD1
0507 21 B5AE 860        LXI  H,XX
050A CD 641F 861        CALL FOF4
                        862 ;
050D 11 B5AA 863        LXI  D,YY1              ;YY=YY*(YY/(XX*DU2M))
0510 21 B2AA 864        LXI  H,FACEPT
0513 CD 8F1F 865        CALL FDIV2
0516 21 B2AE 866        LXI  H,YY
0519 CD 781F 867        CALL FSUB1
051C 21 B5AA 868        LXI  H,DU2M
051F CD 941F 869        CALL FDIV1
0522 21 B2A6 900        LXI  H,YY
0525 CD 671F 901        CALL FADD1
0528 21 B2AB 902        LXI  H,YY
052B CD 641F 903        CALL FOF4
                        904 ;
052E 11 B5AC 905        LXI  D,XX               ;GRA=1.+(XX/YY)**0.5
0531 21 B2AE 906        LXI  H,YY
0534 CD 8F1F 907        CALL FDIV2
0537 3E 01   908        MVI  A,FASCAT
0539 32 C1UE 909        STA  MATHC
053C 21 B2AA 910        LXI  H,GRATIO
053F CD 641F 911        CALL FOF4
                        912 ;
0542 11 B2AA 913        LXI  D,XDUNET           ;XDUNET=XDUNET/FACEPT
0545 21 B2AA 914        LXI  H,FACEPT
0548 CD 8F1F 915        CALL FDIV2
054B 21 B2AA 916        LXI  H,XDUNET
054E CD 641F 917        CALL FOF4
                        918 ;
0551 11 B2AA 919        LXI  D,YDUNET           ;YDUNET=YDUNET/FACEPT
0554 21 B2AA 920        LXI  H,FACEPT
0557 CD 8F1F 921        CALL FDIV2
055A 21 B2AA 922        LXI  H,YDUNET
055D CD 641F 923        CALL FOF4
                        924 ;
0560 11 B2AA 925        LXI  D,XDUNET           ;XDUC=XDUC+(XDUNET-ADC)/DU2M
0563 21 B6AE 926        LXI  H,XDUC
0566 CD 781F 927        CALL FSUB2
0569 21 B5AA 928        LXI  H,DU2M
056C CD 941F 929        CALL FDIV1
056F 21 B6AE 930        LXI  H,XDUC
0572 CD 671F 931        CALL FADD1
0575 21 B6AE 932        LXI  H,XDUC
0578 CD 641F 933        CALL FOF4
                        934 ;
057B 11 B2AA 935        LXI  D,YDUNET           ;YDUC=YDUC+(YDUNET-YDUC)/DU2M
057E 21 B6AC 936        LXI  H,YDUC
0581 CD 781F 937        CALL FSUB2
0584 21 B5AA 938        LXI  H,DU2M
0587 CD 941F 939        CALL FDIV1
058A 21 B6AC 940        LXI  H,YDUC
058D CD 671F 941        CALL FADD1
0590 21 B6AC 942        LXI  H,YDUC
0593 CD 641F 943        CALL FOF4
```

```
                        944 ;
                        945 ;  UPDATE FREQUENCY AVERAGE
                        946 ;
0553 11 3AAB            947         LXI   D,FREXP1          ;IF(FREXP1.LE.(FREQ2N+FREQ2N)) FREQ2N=FREQ2N+FREQ2N
0556 21 2190            948         LXI   H,FREXP2
0559 CD 701F            949         CALL  FSUB2
055C CD F71F            950         CALL  MSTAT
055F E6 40              951         ANI   40H
0561 CA 7305            952         JZ    U3
0564 11 0090            953         LXI   D,.5
0567 21 3AAB            954         LXI   H,FREXP1
056A CD 621F            955         CALL  FADD2
056D 21 3AAB            956         LXI   H,FREXP1
0570 CD C41F            957         CALL  PUP4
                        958 ;
0573 11 3AAB            959 U3:     LXI   D,FREXP1          ;IF(FREXP1.GE.(FREQ2N+FREQ2N)) FREQ2N=FREQ2N+FREQ2N
0576 21 3AAB            960         LXI   H,FREXP1
0579 CD AD1F            961         CALL  PUSH4
057C 21 DEAA            962         LXI   H,FREQ2N
057F 11 DEAA            963         LXI   D,FREQ2N
0582 CD 621F            964         CALL  FADD2
0585 CD 701F            965         CALL  FSUB
0588 CD F71F            966         CALL  MSTAT
058B E6 40              967         ANI   40H
058D C2 9F05            968         JNZ   U4
0590 21 DEAA            969         LXI   H,FREQ2N
0593 11 DEAA            970         LXI   D,FREQ2N
0596 CD 621F            971         CALL  FADD2
0599 21 DEAA            972         LXI   H,FREQ2N
059C CD C41F            973         CALL  PUP4
                        974 ;
059F 11 BEAA            975 U4:     LXI   D,TMETAT          ;TMETAT=TMETAT/FREQ2N
05A2 21 B2AA            976         LXI   H,NFRCEP1
05A5 CD BF1F            977         CALL  FDIV2
05A8 21 DEAA            978         LXI   H,TMETAT
05AB CD C41F            979         CALL  PUP4
                        980 ;
05AE 11 BEAA            981         LXI   D,TMETAT          ;TMETA=TMETA+(TMETAT-TMETA)/FREQ2N
05B1 21 91AB            982         LXI   H,TMETA
05B4 CD 701F            983         CALL  FSUB2
05B7 21 DEAA            984         LXI   H,FREQ2N
05BA CD 941F            985         CALL  FDIV1
05BD 21 91AB            986         LXI   H,TMETA
05C0 CD 671F            987         CALL  FADD1
05C3 21 91AB            988         LXI   H,TMETA
05C6 CD C41F            989         CALL  PUP4
                        990 ;
05C9 11 2990            991         LXI   D,SAMPLEF         ;FREQ=SAMPLEF*TMETA/TWOPI
05CC 21 91AB            992         LXI   H,TMETA
05CF CD B11F            993         CALL  FMULT
05D2 21 3190            994         LXI   H,TWOPI
05D5 CD 941F            995         CALL  FDIV1
05D8 21 A6AE            996         LXI   H,FREQ
05DB CD C41F            997         CALL  PUP4
                        998 ;
                        999 ;  UPDATE CROSS CORRELATION AVERAGE
                       1000 ;
05DE 3A 2F2A           1001         LDA   CROSSN
05E1 F6 00             1002         ORI   00H
05E3 CA 3A06           1003         JZ    L140              ;IF (CNDT. CROSSN) GO TO 140
```

```
                        004 ;
05E6 21 B5AA 005            LXI  H,ERRTERM      ;ATTACH MEM MELT IF ERRTERM
05E9 CD 7D1F 006            CALL FLOAT
05EC CD F71F 007            CALL FSTAT
05EF E6 C0   008            ANI  0C0H           ;IF(ATTERMS .EQ. 0/0D0 TO 150
05F1 C2 3B0A 009            JNZ  L130
05F4 21 B5AA 010            LXI  H,ERRTERM      ;ERRTERM = FLOAT( ERMS)
05F7 CD C41F 011            CALL FDF4
                        012 ;
05FA 3E 32   013            MVI  A,50
05FC 32 252A 014            STA  DUJ
05FF 11 582A 015            LXI  D,RMET4        ;DE=.RMET(J)
0602 21 0EAA 016            LXI  H,RMET+4       ;HL=.RMET(J)
0605 01 0400 017            LXI  B,0004H        ;DELTA=INCREMENT FOR DE AND HL
0608 EB      018 LUUP:      XCHG                ;RMET(J)=RMET(J)/ERRTERMS
0609 E5      019            PUSH H
060A D5      020            PUSH D              ;STACK NOW HAS RMET FOLLOWED BY A
060B 21 B6AA 021            LXI  H,ERRTERM
060E CD 8F1F 022            CALL FDIV2
0611 E1      023            POP  H              ;H-L == RMET
0612 CD C41F 024            CALL FDF4
0615 E1      025            POP  H              ;H-L == A          D-E == RMET
0616 CD 701F 026            CALL FSUB2          ;A(J)=A(J)/(RMET(J)-ERRTERMS)
0619 E5      027            PUSH H
061A 21 00AA 028            LXI  H,ONE
061D CD F41F 029            CALL FDIV1
0620 E1      030            POP  H              ;H-L == A(J)
0621 CD 6A1F 031            CALL FADD1          ;H-L REMAINS UNCHANGED
0624 CD C41F 032            CALL FDF4
0627 EB      033            XCHG                ;D-E == NEXT A       H-L == RMET
0628 09      034            DAD  B              ;H-L == NEXT RMET
0629 3A 252B 035            LDA  DUJ            ;DECREMENT LOOP COUNTER
062C 3D      036            DCR  A
062D 32 252B 037            STA  DUJ
0630 C2 0B0A 038            JNZ  LUUP
0633 3E 01   039            MVI  A,01H
0635 32 222B 040            STA  DFLAG
0638 C9      041 L130.      RET
                        042 ;
                        043 ;  UPDATE SLOPE AVERAGE
                        044 ;
0639 3A 282B 045 L140:      LDA  SLOPEA         ;IF(.NOT. SLOPEA) GO TO 150
063C F6 00   046            ORI  00H
063E CA 8C0A 047            JZ   L150
                        048 ;
0641 11 1EAA 049            LXI  D,USEXP1       ;IF(USEXP1.LT.(PSE. USEXP1=USEXP1+1
0644 21 1BA0 050            LXI  H,PRUSE
0647 CD 701F 051            CALL FSUB2
064A CD F71F 052            CALL FSTAT
064D E6 40   053            ANI  40H
064F CA 8106 054            JZ   U5
0652 11 0000 055            LXI  D, ONE
0655 21 1EAA 056            LXI  H,USEXP1
0658 CD 6A1F 057            CALL FADD2
065B 21 1EAA 058            LXI  H,USEXP1
065E CD C41F 059            CALL FDF4
                        060 ;
0661 11 1EAA 061 U5:        LXI  D,USEXP1       ;IF(USEXP1.GE.(1.0+DISPCN*DISPCN)) DISPCN=DISPCN+DISPCN
0664 21 00AA 062            LXI  H,DISPCN
0667 CD 701F 063            CALL FSUB2
```

```
                        ;
                        ;  UPDATE SKEW AVERAGE
                        ;
06BD 3A 2A2B    098 L150:   LDA  SKEWA          ;IF(.NOT. SKEWA) GO TO L260
06C0 B7         099         ORA  A
06C1 CA D307    100         JZ   L260
                101 ;
06C5 11 B5A8    102         LXI  D,SKEWX1       ;IF(SKEWX(I).LT.MSKEW) SKEWX(I)=SKEWX(I)+1
06C8 21 2B70    103         LXI  H,MSKEW
06CB CD 701F    104         CALL FSUB2
06CE CD F71F    105         CALL RSTAT
06D1 E6 40      106         ANI  40H
06D3 CA E506    107         JZ   U7
06D6 11 0040    108         LXI  D,64
06D9 21 B5A8    109         LXI  H,SKEWX1
06DC CD 621F    110         CALL FADD2
06DF 21 B5A8    111         LXI  H,SKEWX1
06E2 CD C41F    112         CALL PUP4
                113 ;
06E5 11 B5A8    114 U7:     LXI  D,SKEWX1       ;IF(SKEWX(I).GE.SKEW) SKEWX(I)=SKEWX(I)-SKEW
06E8 21 2B70    115         LXI  H,MSKEW
06EB CD 701F    116         CALL FSUB2
06EE 21 B5A8    117         LXI  H,SKEWX1
06F1 CD 781F    118         CALL FSUB1
06F4 CD F71F    119         CALL RSTAT
06F7 E6 40      120         ANI  40H
06F9 C2 0B07    121         JNZ  U8
06FC 11 B5A8    122         LXI  D,SKEWX1
06FF 21 B5A8    123         LXI  H,SKEWX1
```

```
                        CALL FDUP2
0705 11 E61F 125        LXI  H,SK2N
0708 CD C41F 126        CALL FOP4
                        127 ;
070B 11 2990 128 UB:    LXI  D,SAMPLFR      ;SCALE1=SAMPLFR/FALERT
070E 21 E6AA 129        LXI  H,FALERT
0711 CD 8F1F 130        CALL FDIV2
0714 21 7CA6 131        LXI  H,SCALE1
0717 CD C41F 132        CALL FOP4
                        133 ;
071A 11 7CA6 134        LXI  D,SCALE1       ;SCALE2=SCALE1*SAMPLFR
071D 21 2990 135        LXI  H,SAMPLFR
0720 CD 811F 136        CALL FMUL2
0723 21 80A8 137        LXI  H,SCALE2
0726 CD C41F 138        CALL FOP4
                        139 ;
0729 11 A2AA 140        LXI  D,DUXDY1       ;DUXDY1=DUXDY1*SCALE2*SAMPLFR
072C 21 2990 141        LXI  H,SAMPLFR
072F CD 811F 142        CALL FMUL2
0732 21 80A8 143        LXI  H,SCALE2
0735 CD 661F 144        CALL FMUL1
0738 21 A2AA 145        LXI  H,DUXDY1
073B CD C41F 146        CALL FOP4
                        147 ;
073E 11 ALAA 148        LXI  D,DDXDXY1      ;DDXDXY1=DUXDY1*(DUXDY1-DUXDX1)/SK2N
0741 21 16A8 149        LXI  H,DDXDXY
0744 CD 701F 150        CALL FSUB2
0747 21 E6AA 151        LXI  H,SK2N
074A CD Y41F 152        CALL FDIV1
074D 21 16A8 153        LXI  H,DDXDXY
0750 CD 671F 154        CALL FMUL1
0753 21 16A8 155        LXI  H,DDXDXY
0756 CD C41F 156        CALL FOP4
                        157 ;
0759 11 A6AA 158        LXI  D,DXDX1        ;DXDX1=DXDX1*SCALE2
075C 21 80A8 159        LXI  H,SCALE2
075F CD 811F 160        CALL FMUL2
0762 21 A6AA 161        LXI  H,DXDX1
0765 CD C41F 162        CALL FOP4
                        163 ;
0768 11 A6AA 164        LXI  D,DXDX1        ;DXDX=DXDX+(DXDX1-DXDX)/SK2N
076B 21 26A8 165        LXI  H,DXDX
076E CD 701F 166        CALL FSUB2
0771 21 E6AA 167        LXI  H,SK2N
0774 CD Y41F 168        CALL FDIV1
0777 21 26A8 169        LXI  H,DXDX
077A CD 671F 170        CALL FMUL1
077D 21 26A8 171        LXI  H,DXDX
0780 CD C41F 172        CALL FOP4
                        173 ;
0783 11 AEAA 174        LXI  D,DYDY1        ;DYDY1=DYDY1*SCALE2
0786 21 80A8 175        LXI  H,SCALE2
0789 CD 811F 176        CALL FMUL2
078C 21 AEAA 177        LXI  H,DYDY1
078F CD C41F 178        CALL FOP4
                        179 ;
0792 11 AEAA 180        LXI  D,DYDY1        ;DYDY=DYDY+(DYDY1-DYDY)/SK2N
0795 21 2EA8 181        LXI  H,DYDY
0798 CD 701F 182        CALL FSUB2
079B 21 E6AA 183        LXI  H,SK2N
```

```
07AE CD F41F 184                CALL FDIV1
07A1 21 .EA5 185                LXI  H,YDX1
07A4 CD 671F 186                CALL FADD1
07A7 21 2EAA 187                LXI  H,YDX1
07AA CD E41F 188                CALL PUP4
                  189 ;
07AD 11 CEAA 190                LXI  D,YDX1         ;YDX1=YDX1*(SCALE1-YDX1/SK2N
07B0 21 7CA8 191                LXI  H,SCALE1
07B3 CD B11F 192                CALL FMUL2
07E6 21 C2A6 193                LXI  H,YDX
07B9 CD 781F 194                CALL FSUB1
07BC 21 E6AA 195                LXI  H,SK2N
07BF CD 941F 196                CALL FDIV1
07C2 21 C2A8 197                LXI  H,YDX
07C5 CD 671F 198                CALL FADD1
07C8 21 C2A8 199                LXI  H,YDX
07CB CD E41F 200                CALL PUP4
07CE 3E 01   201                MVI  A,01H
07D0 32 322B 202                STA  UFLAG
07D3 C9      203 L260:          RET
                  204 ;
                  205 ;SUBROUTINE JUMP TABLE
                  206 ;
      07D4        207             PJTABS EQU  $           ;START OF FROM SUBROUTINE JMP TABLE
                  208 ;
07D4 C3 3990 209                PSTART:JMP  ASTART
07D7 C3 5B92 210                PINITA:JMP  AINITA
07DA C3 6D90 211                PSCHED:JMP  ASCHED
07DD C3 A300 212                PPROCE:JMP  APROCE
07E0 C3 3B04 213                PUPDAT:JMP  AUPDAT
07E3 C3 A1Y4 214                PDISPL:JMP  ADISPL
                  215 ;
      07E6        216             PJTABE EQU  $           ;END OF FROM SUBROUTINE JMP TABLE
                  217             END
```

```
A       0007    ABLOS   0006    ABSIA   0005    AATAM   0007    ACHSU   0034
ACHSF   0015    ACHSS   0074    ACLOS   0005    ADADD   002C    ADDIV   002F
ADISFL  v4A1    ADMUL   002E    ADMOD   003e    ADSUB   002B    AEXP    000A
AFADD   0010    AFDIV   0013    AFIXD   001E    AFIXS   001F    AFLTD   001C
AFLTS   001D    AFMUL   0012    AFSUB   0011    AINITA  v23B    ALN     0009
ALOG    000B    AMOD    0000    ARUPD   0038    AFOFF   0016    AFOS    0078
AFTOLE  0043    AFTOD   0037    AFTOF   0017    AFOS    0077    AFUP1   0016
AFWR    000F    ASADD   0060    ASCMED  v06D    ASDIV   006F    ASIN    0002
ASMUL   0065    ASMOD   0076    ASSUB   0001    ASSUB   0061    ASTANT  V037
ATAN    0004    ATODIF  2B31    ATOFF   2B2E    AUPDN1  043B    AXCHG   0039
AXCHR   0019    AXCHS   0079    B       0000    BEGIN   1e43    BUFFER  0800
C       0001    CALCF   0129    CALCL   0125    CC1     024F    CC2     027F
CC3     02A3    CC4     0202    CC5     0205    CC6     0309    CC7     0307
CCB     032V    CC9     032C    CCONNS  9018    CLTIME  A602    CLEVEL  7006
CLUCKA  2B26    CM2     A806    CSUM    7001    D       0002    D2      014F    DATA    1000
DC2M    AAD6    DCEXPF  A80E    DDX     AB12    DDXDY   A816    DDXDYN  AYA6
DDXDY1  AAA2    DDY     A814    DIFND   0066    DISPCM  AHDA    DISPLY  7034
DDJ     2B25    DSEXPF  AB1E    DX      AB22    DXDX    A826    DXDXN   A70A
DXDX1   AAA6    DXDYN   A9AE    DXDY1   AAAH    DY      A82A    DYDY    AB2E
DYDYN   A9E2    DYDY1   AAAL    E       0005    ENKU    1820    ENKSUB  1839
FALEPT  AAB2    FDIV    1F6A    FADD1   1F67    FADD2   1F62    FDIV    1F97
FDIV1   1F94    FDIVC   1F8F    FLOAT   1F9D    FLOAT1  1F67    FLTAX   70L7
FLTRT   7019    FMAX    AB3C    FMUL    1FE9    FMUL1   1F86    FMUL2   1F81
FMLITE  3800    FPSW    0000    FREC    AB3e    FRECCM  AADE    FREXP1  AB3A
FNEXT   AB3E    FNTEXM  AAB6    FSUB    1F78    FSUB1   1F78    FSUB2   1F70
GEL     A842    GUEIT   2B24    GRAT1D  0012    H       0004    HINIT   1800
IC      0007    INDEX0  2B2F    INDEX1  A846    INDEX2  A848    INITAL  7018
INIT1   005F    IRAM    0072    ISAMPL  A84A    JBLK    1A0F    JMAX    A84B
JMIN    A84F    JPEAK   AB53    L       0003    L130    0638    L140    0639
L150    0e8D    L220    013E    L222    01C7    L223    02B5    L224    035B
L228    03FB    L230    041A    L260    07B3    LF      000A    LUDP    0608
M       0006    MATHC   0801    MATHD   0800    MINSIG  A857    MODE    00LE
MSKE    A858    MSTAT   1FF7    MULL    0091    MXDCE   9019    MXDSE   9011
MXFRE   9021    MXSKE   9025    NALEPT  A9B6    NAY     01AC    NNL     9000
NNLM    9000    OUT     700F    PDISPL  07E3    PIPIZ   A85C    PI2     A860
PI5     Ab64    PI6     Ab6B    PINITN  07D7    PUTARS  07E6    PUTARS  07D4
POP4    1FE4    PPKODE  07DB    PRMPTR  2B2A    PKODES  701E    PSCMED  07D6
PSCNT   2B33    PSTART  07D4    PSW     000b    PUPDAT  07F0    PUSH4   1FAD
K       2A54    RESTAR  1BE9    RUTABS  7015    RMAX    AB6L    RM1R    AB70
RNET    A9DA    RNEW    A9DE    RPEAK   AB74    RSTCM   0000    RTERMS  A9BA
RX      27FC    RX50    2B20    RZERTR  AB7B    RY      2UD4    RYPNTR  6B7A
SCALE1  Ab7C    SCALE2  Ab80    SCMED   701H    SCMPTR  2B2C    SLRA1   7000
SIDL    6801    SIDL2   6001    SK2M    AAE6    SKEW    A8B4    SKEWA   2B29
SPEXPF  Ab55    SLOPE   Ab5L    SLOPE1  2B2B    SLPNET  AABA    SLPNEW  A9BE
SPPLPT  7024    SP      0002    SRUN    0007    STACK   7100    STAPT   7013
TBUFS   A9DA    TEMP    7013    TEMP1   A8A0    TEP     V008    TEST2   0094
TMEPA   A8A1    TMEPAL  A8A5    TMEPAL  9028    TMEPAM  A9L2    TMEPM1  A9BE
TIMER   1L95    TWO     V004    TWOFI   9031    U1      0903    U2      04AY
U3      05F3    U4      059F    U5      0601    U6      0957    U7      05E5
U8      0F0B    UILMD   2B32    UPDATE  A9F4    UPT     A9F2    UPTAP1  A9AE
UPDATE  7021    UPTIME  7029    VMEAN   A855    VMEAN1  A8AD    VMEAN2  A9BE
VBUFS   A802    WASLOP  A8YE    X       A8A6    XA      A836    XACME1  A8L2
XDCNEW  A9C0    XS      A8AA    XX      A8E6    XXP     A9CF    XX1     AAC6
Y       A8BA    YDC     A8BE    YDCNET  A8DA    YDCNEW  A9CE    YDX     A8D2
YDXN    A9D2    YDX1    AALE    YS      A8D6    YY      A8D2    YYR     A9D6
YY1     AAD2
ZLSO    A8DA
ZSO     A8D6
ZSOMIN  V035
```

APPENDIX C

SYNTHESIZER DRAWINGS AND PARTS LISTS

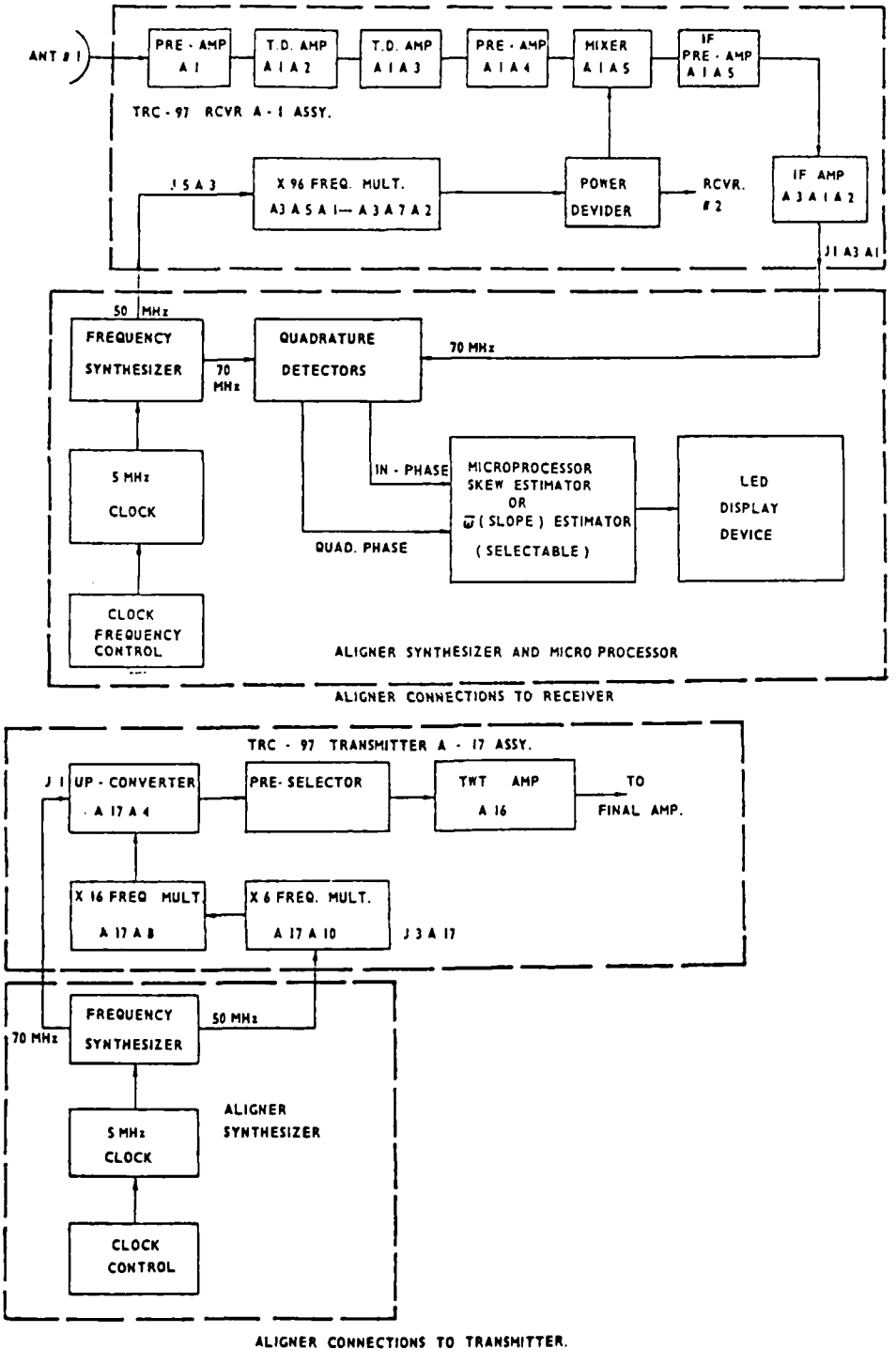


Figure C.1 INTERCONNECTIONS OF ALIGNER AND TRC-97

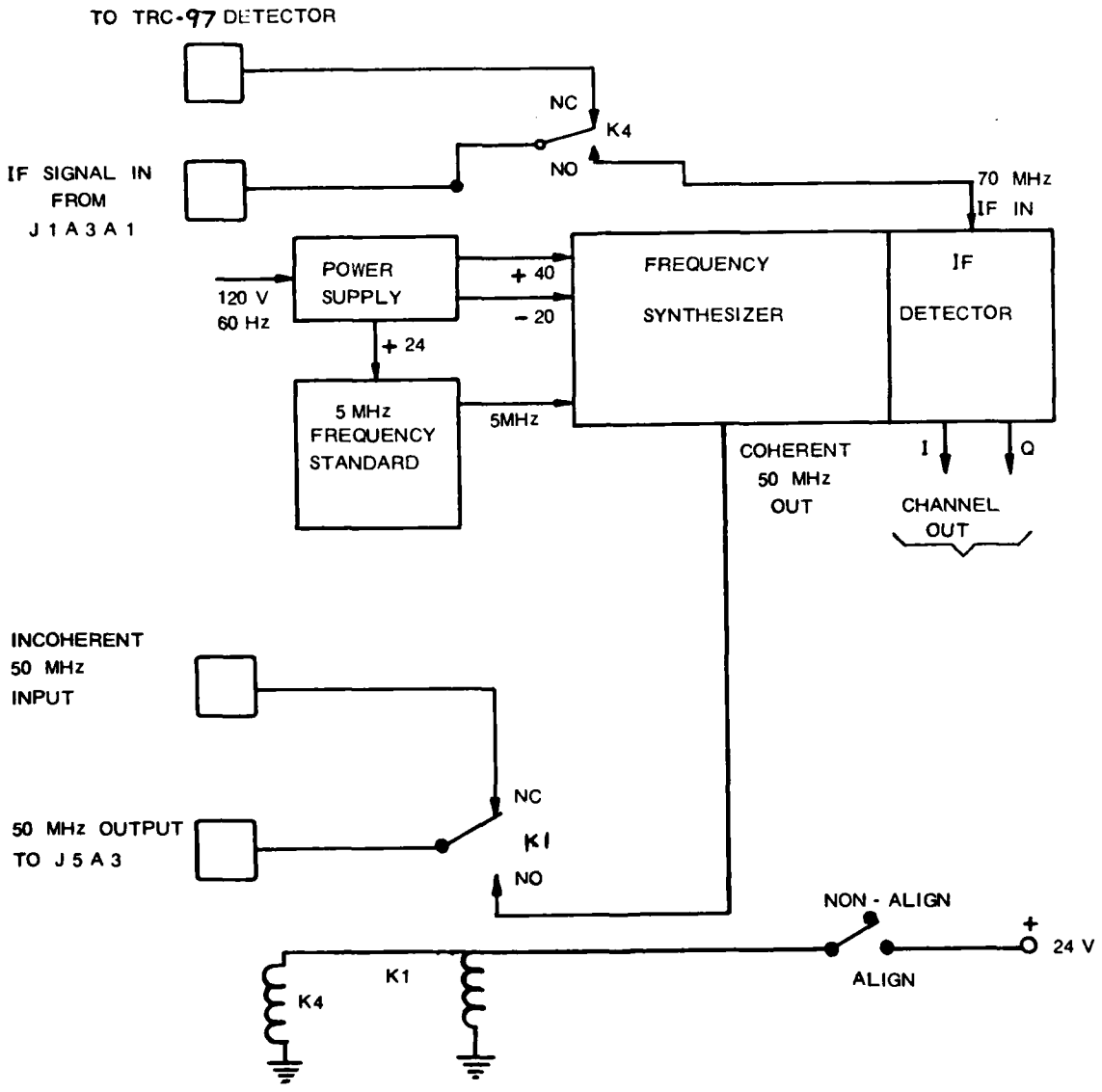


Fig. C.2a SIGNAL LEAD RELAY SWITCHING FOR TRC-97 RECEIVER APPLICATION

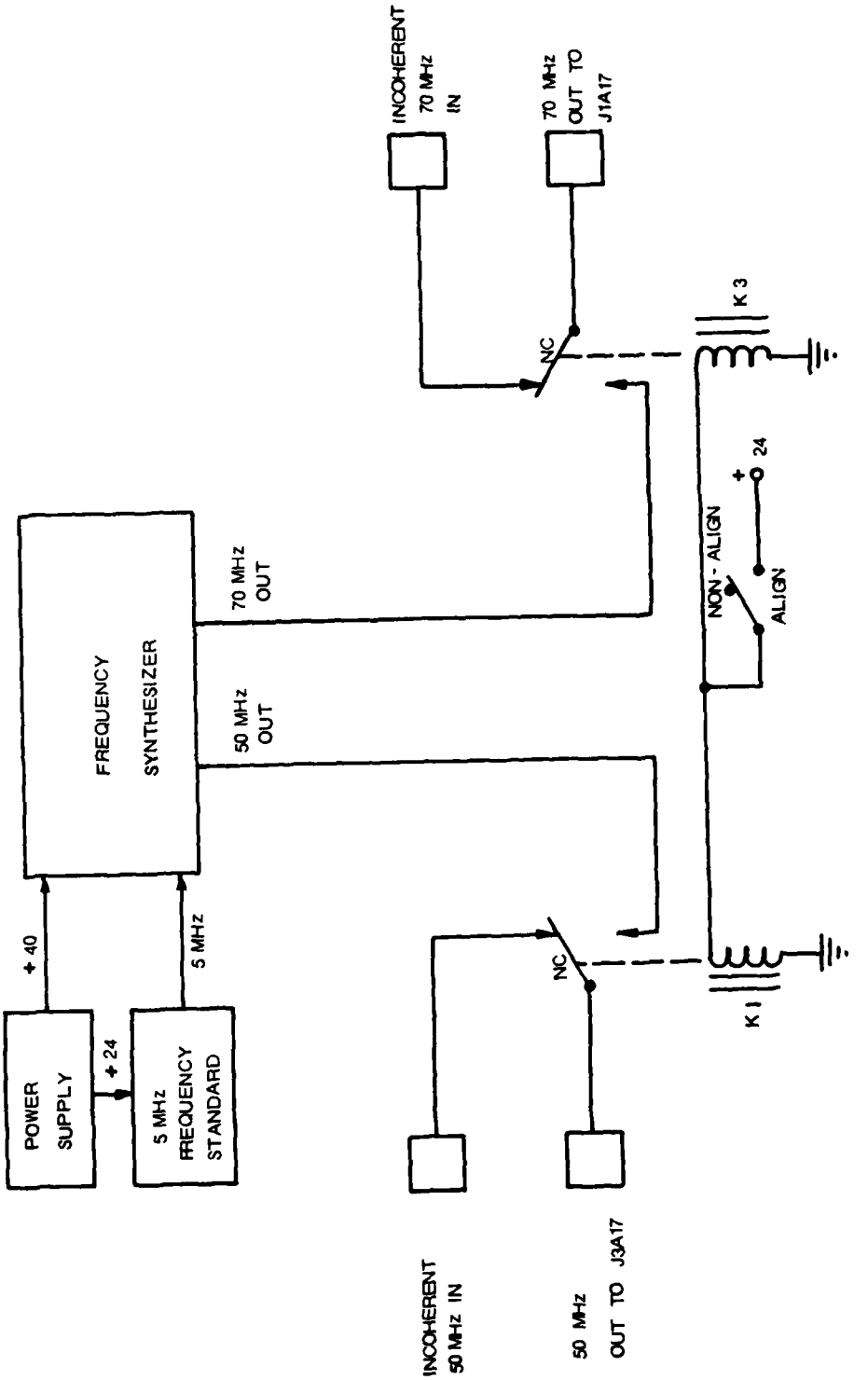


Fig.C2b SIGNAL LEAD RELAY SWITCHING FOR TRC-97 TRANSMITTER APPLICATION

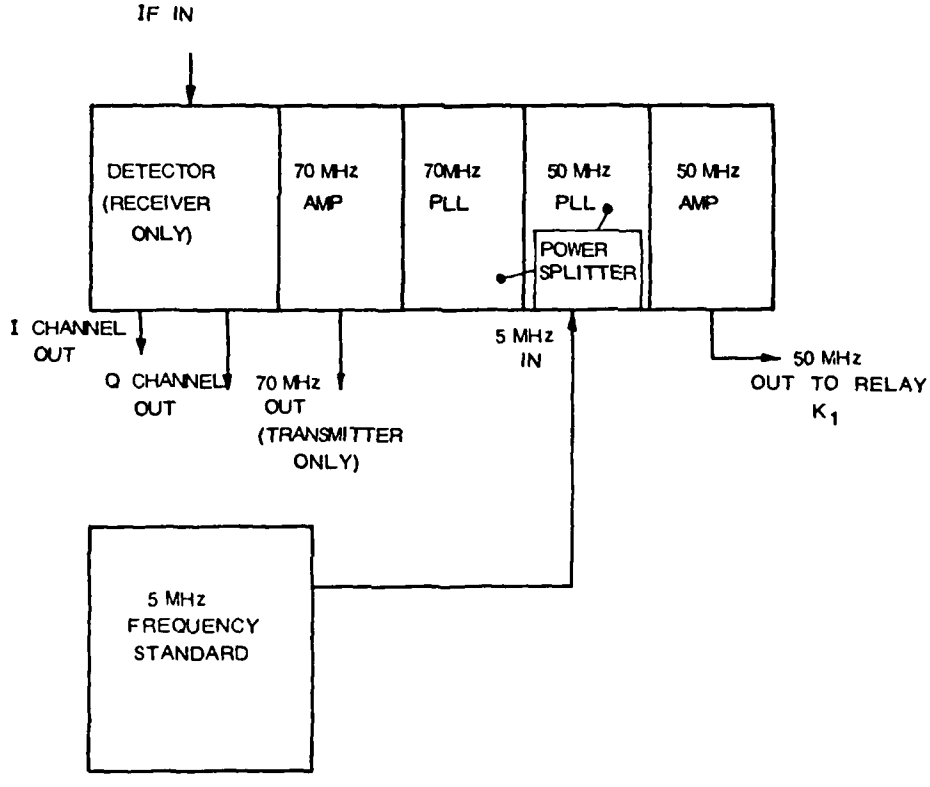


Figure C.3. RECEIVER FREQUENCY SYNTHESIZER BASIC DESIGN

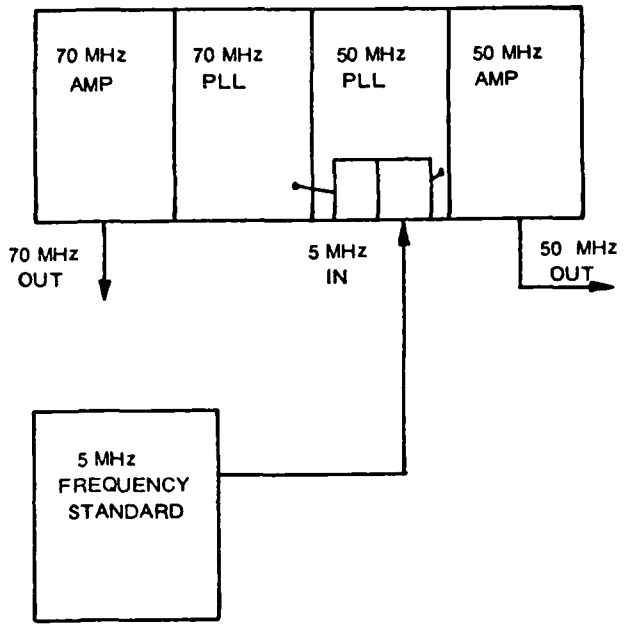


Figure C.4. TRANSMITTER FREQUENCY SYNTHESIZER BASIC DESIGN

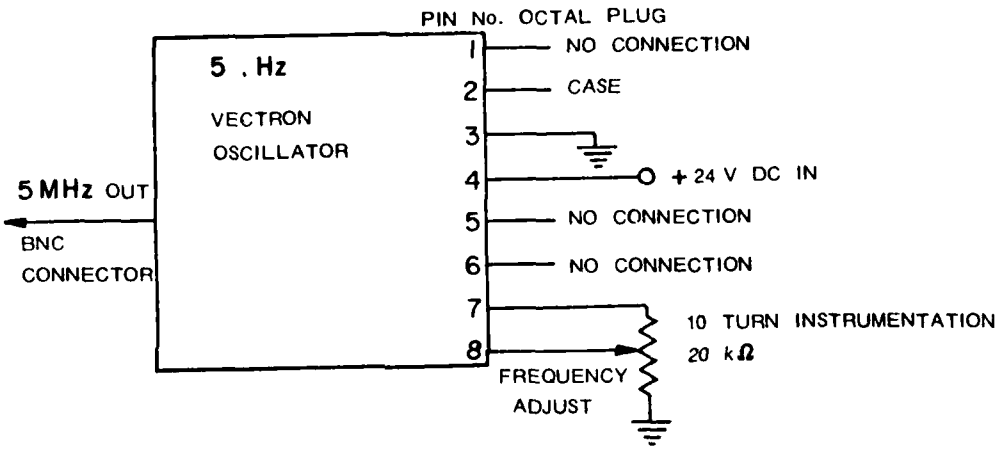


Figure C.5. 5 MHz FREQUENCY STANDARD CONNECTION DIAGRAM

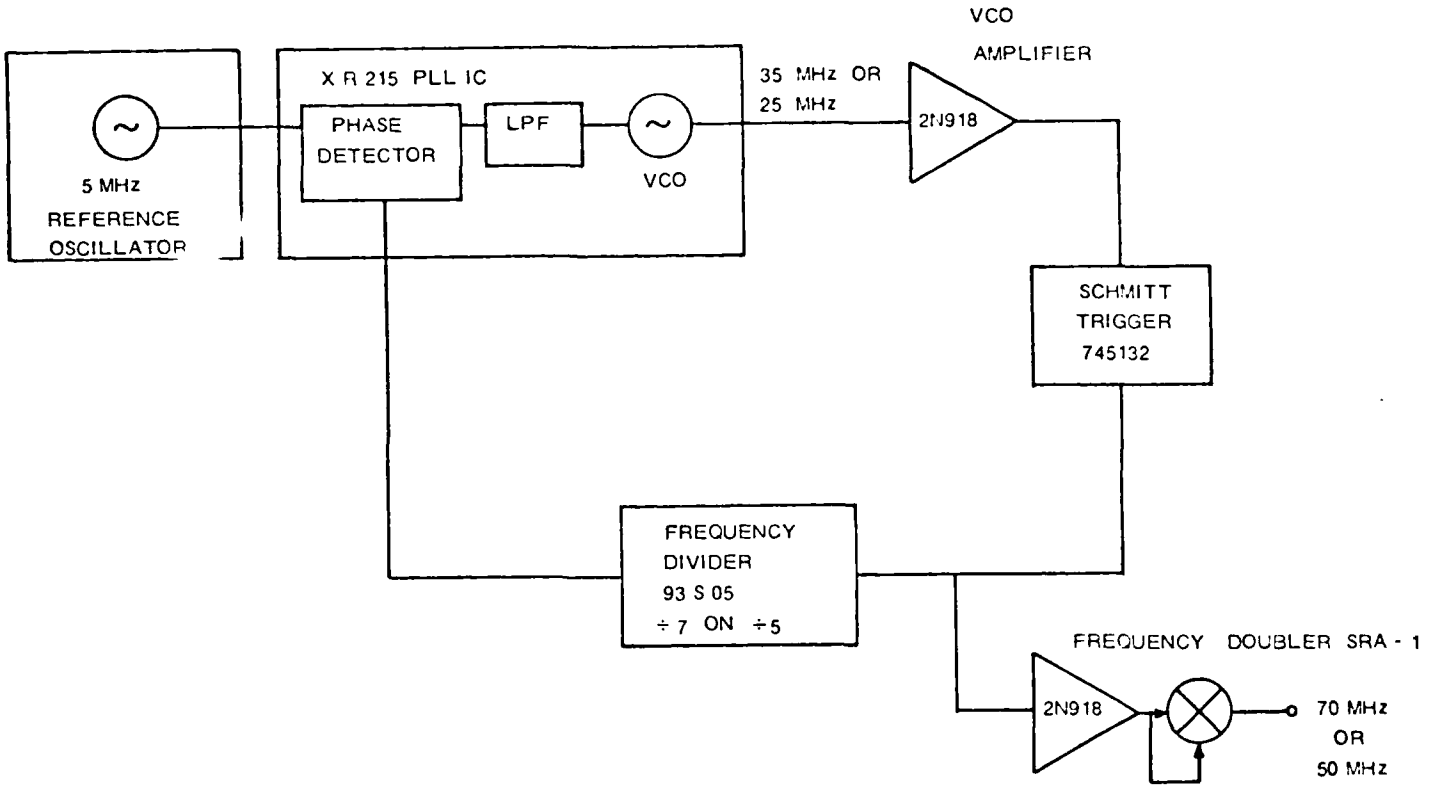


Figure C.6.

BASIC PHASED LOCKED LOOP DESIGN

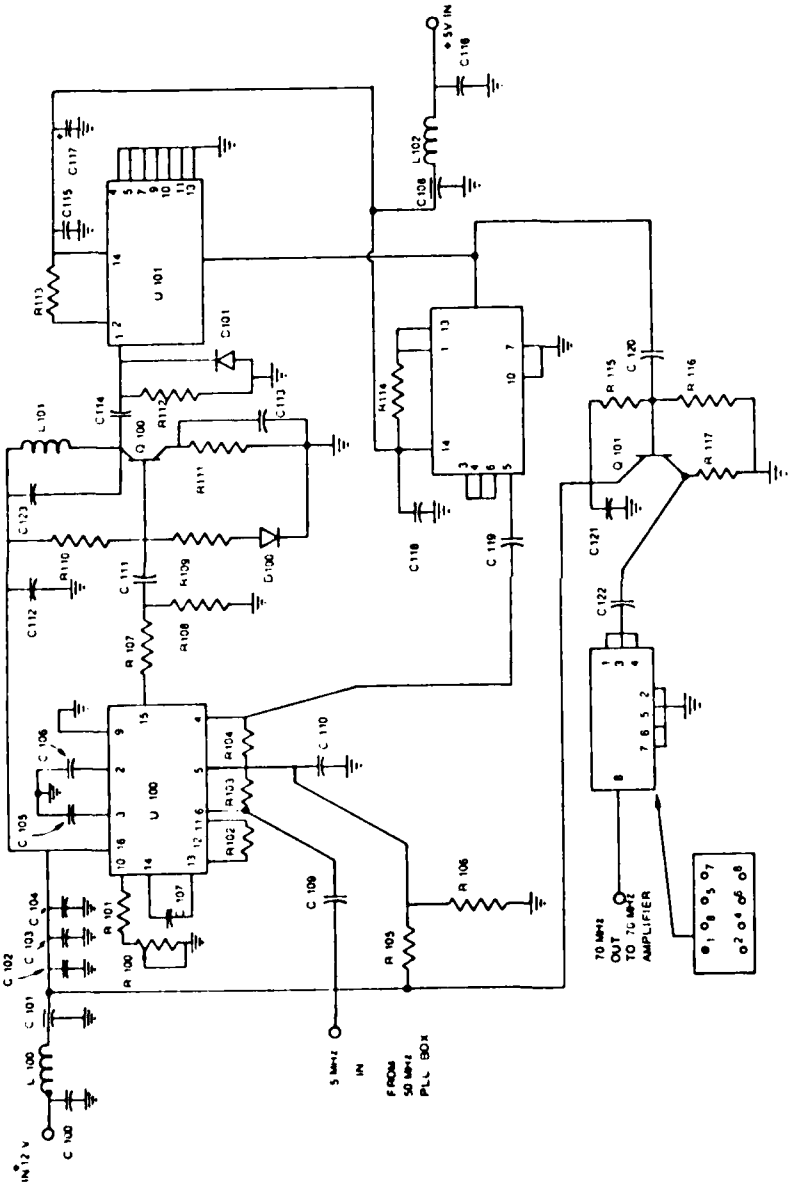


Figure C.7. 70 MHz PHASE LOCKED LOOP

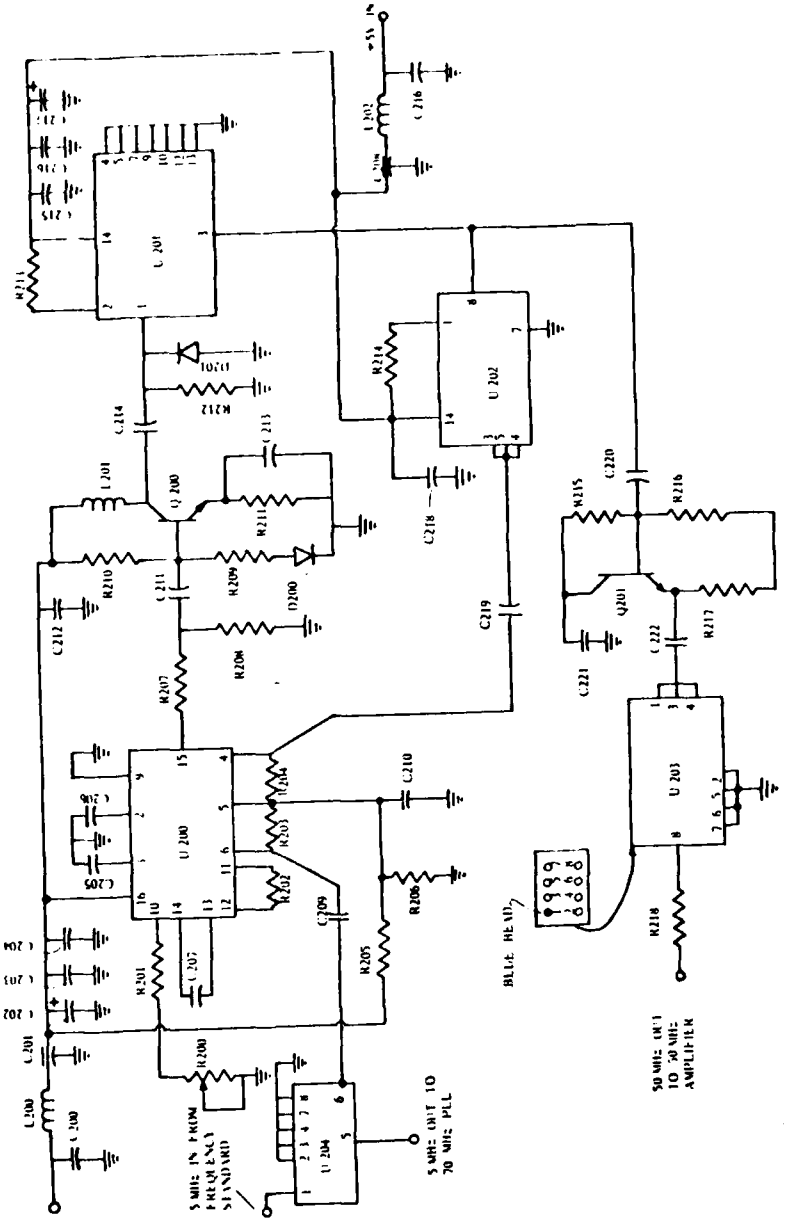


Figure C.8. 50 MHz PHASE LOCKED LOOP

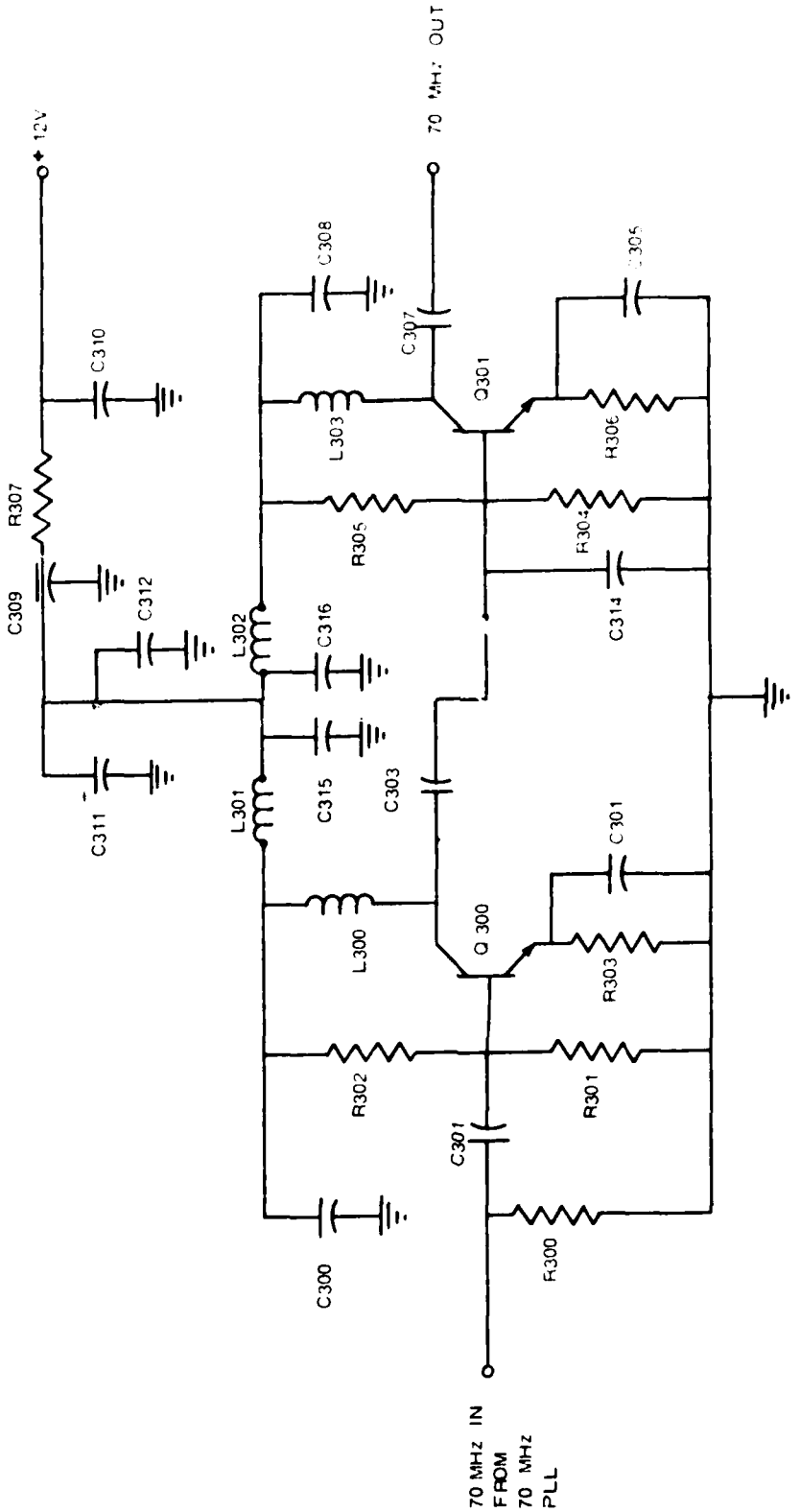


Figure C.9. 70 MHz AMPLIFIER

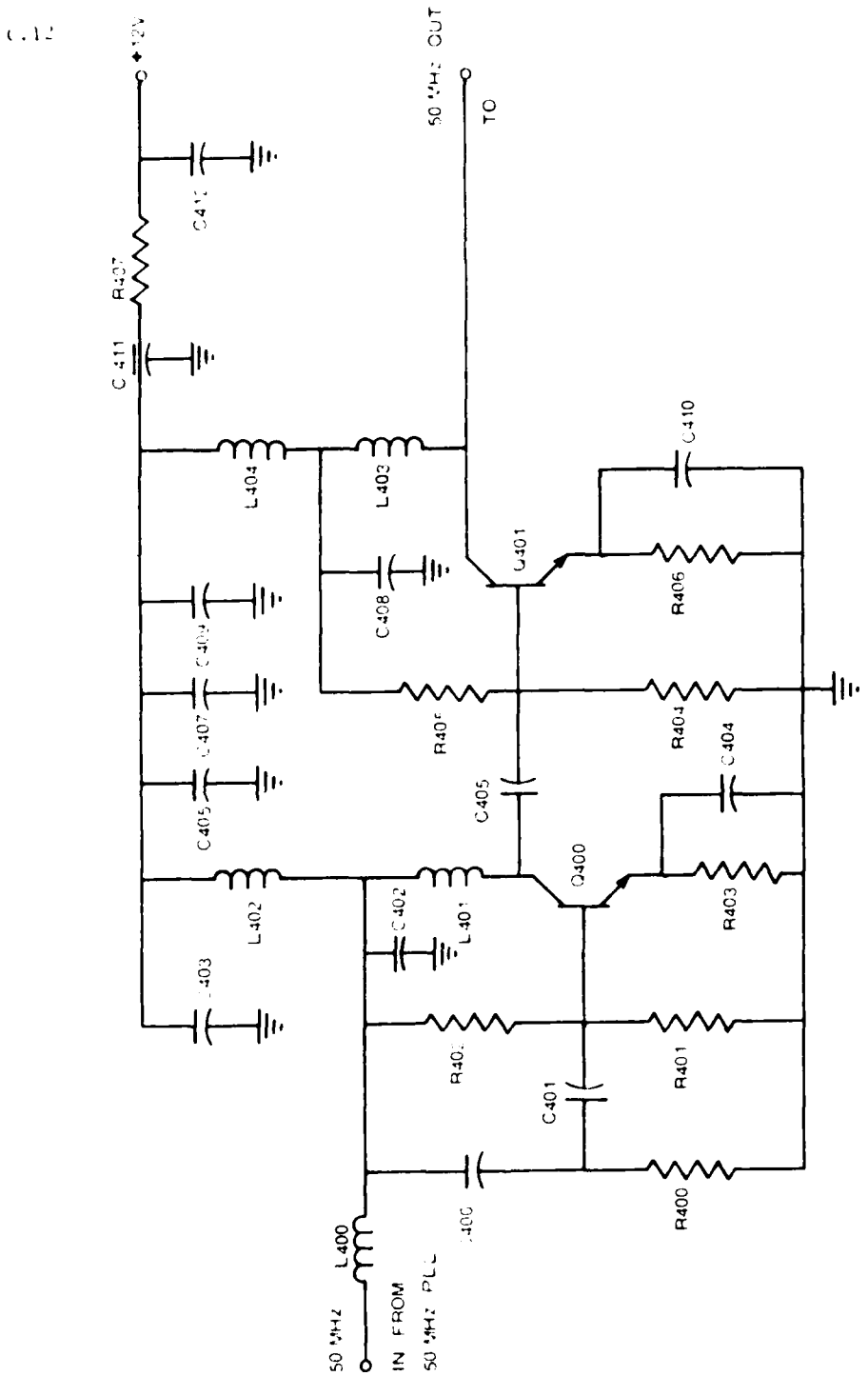


Figure C.10. 50 MHz AMPLIFIER

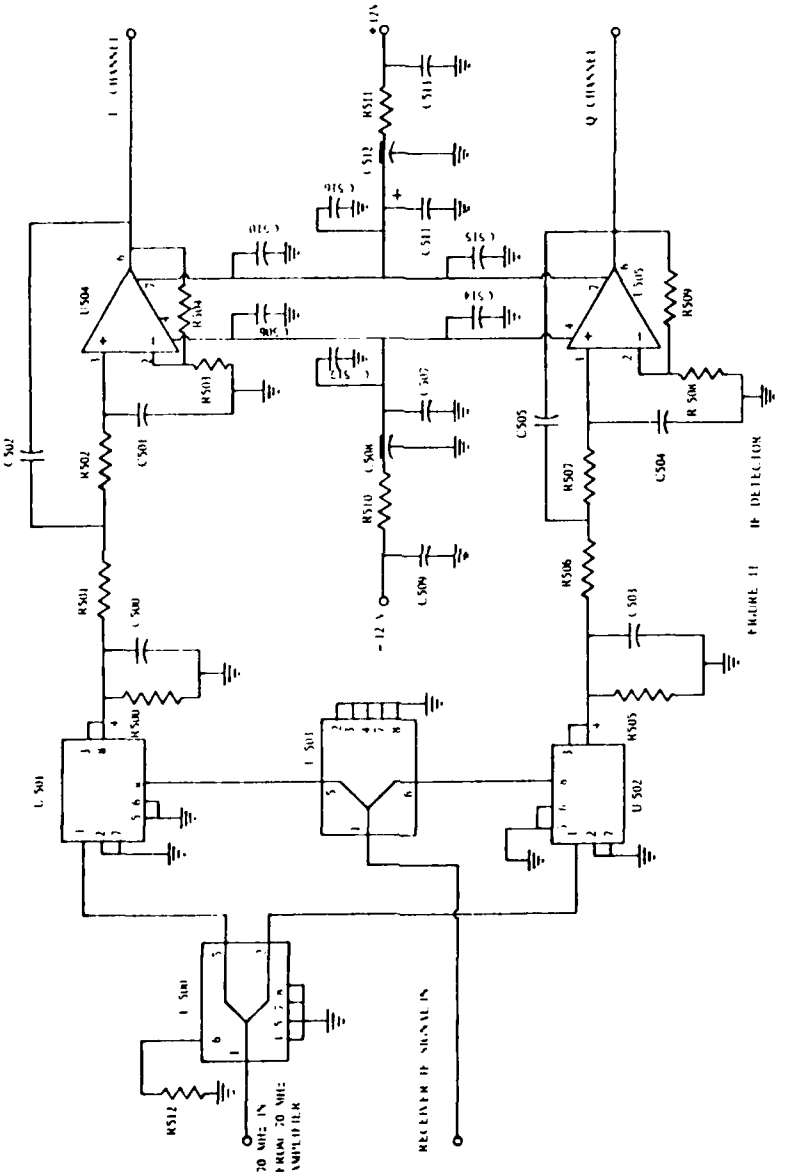


Figure C.11a. DETECTOR AND LOW-PASS FILTER

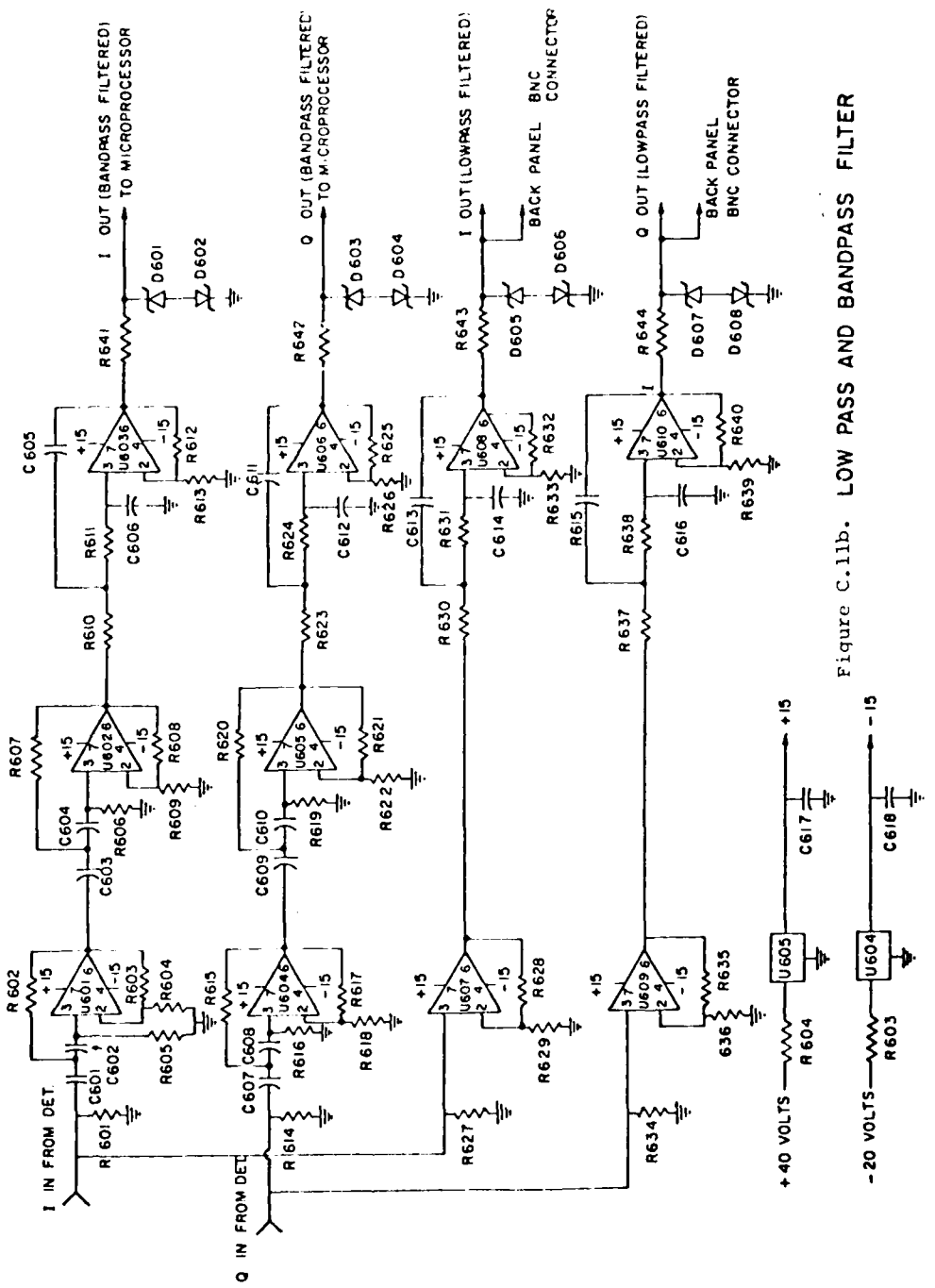


Figure C.11b. LOW PASS AND BANDPASS FILTER

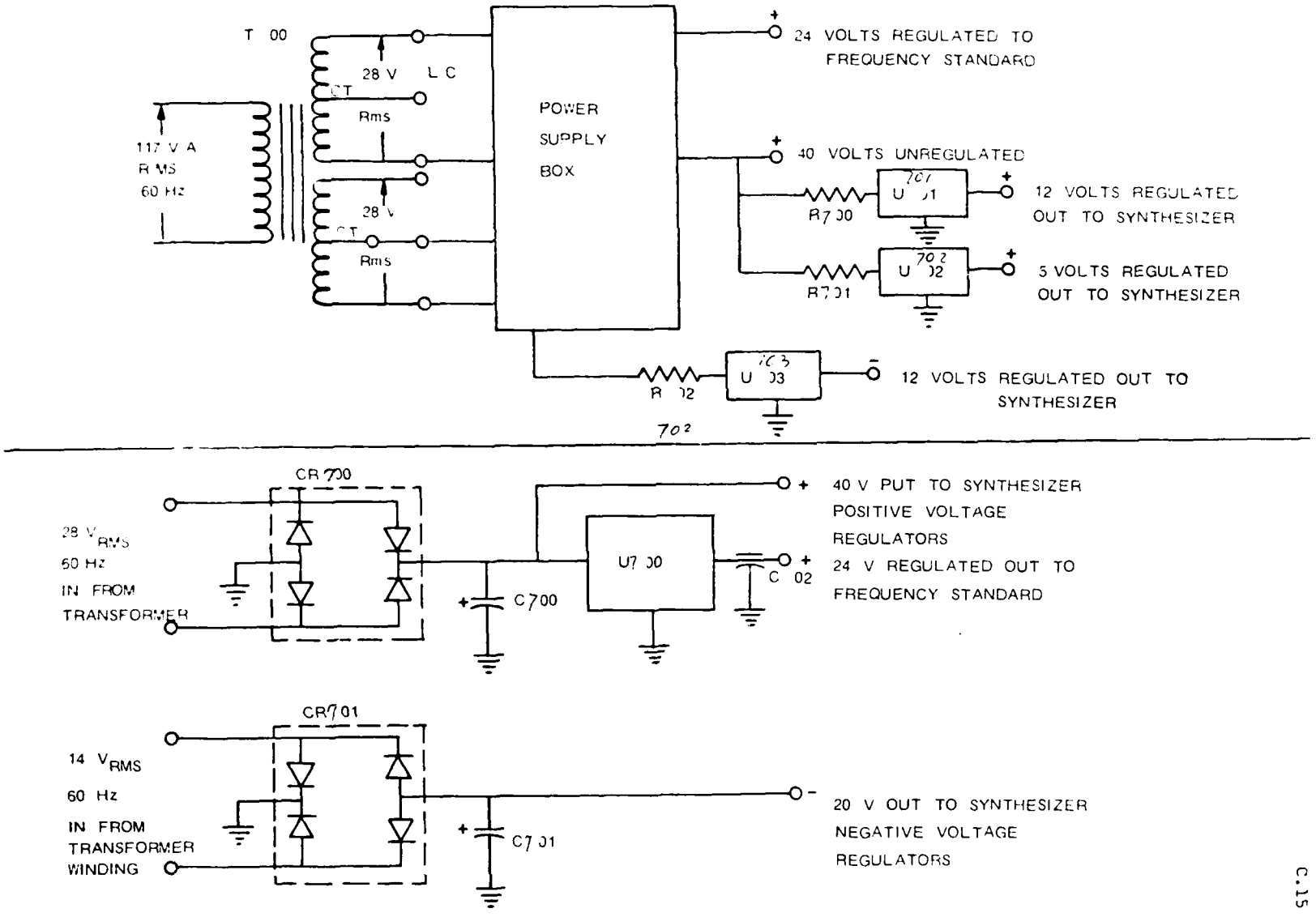


Figure C.12. SCHEMATIC - POWER SUPPLY

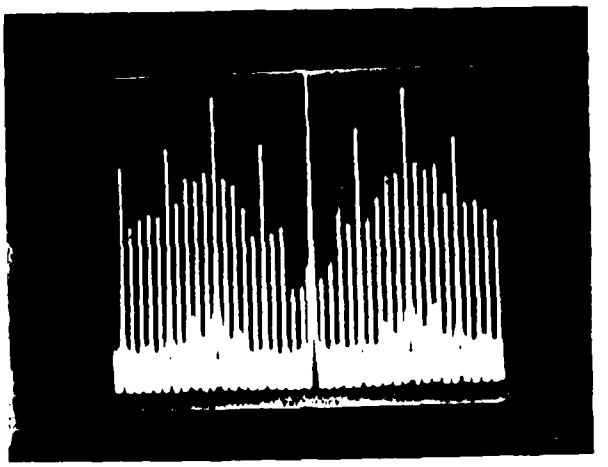


Figure C.13. 50 MHz Amplifier Output Spectrum. Full Scale = 20 dbm; Vertical Scale: 10 db/Div; Horizontal Scale: 10 MHz/Div; Center Freq. = 0 MHz.

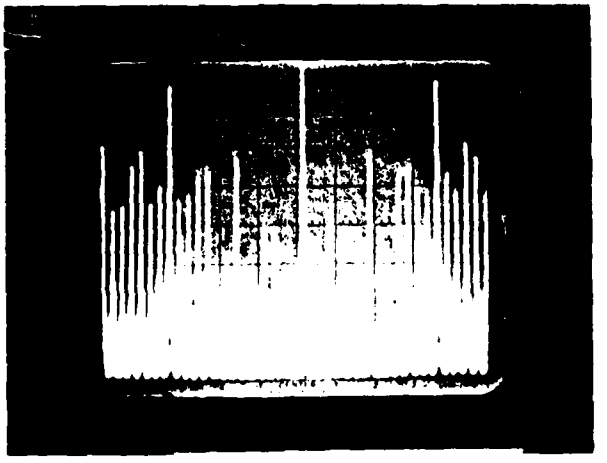
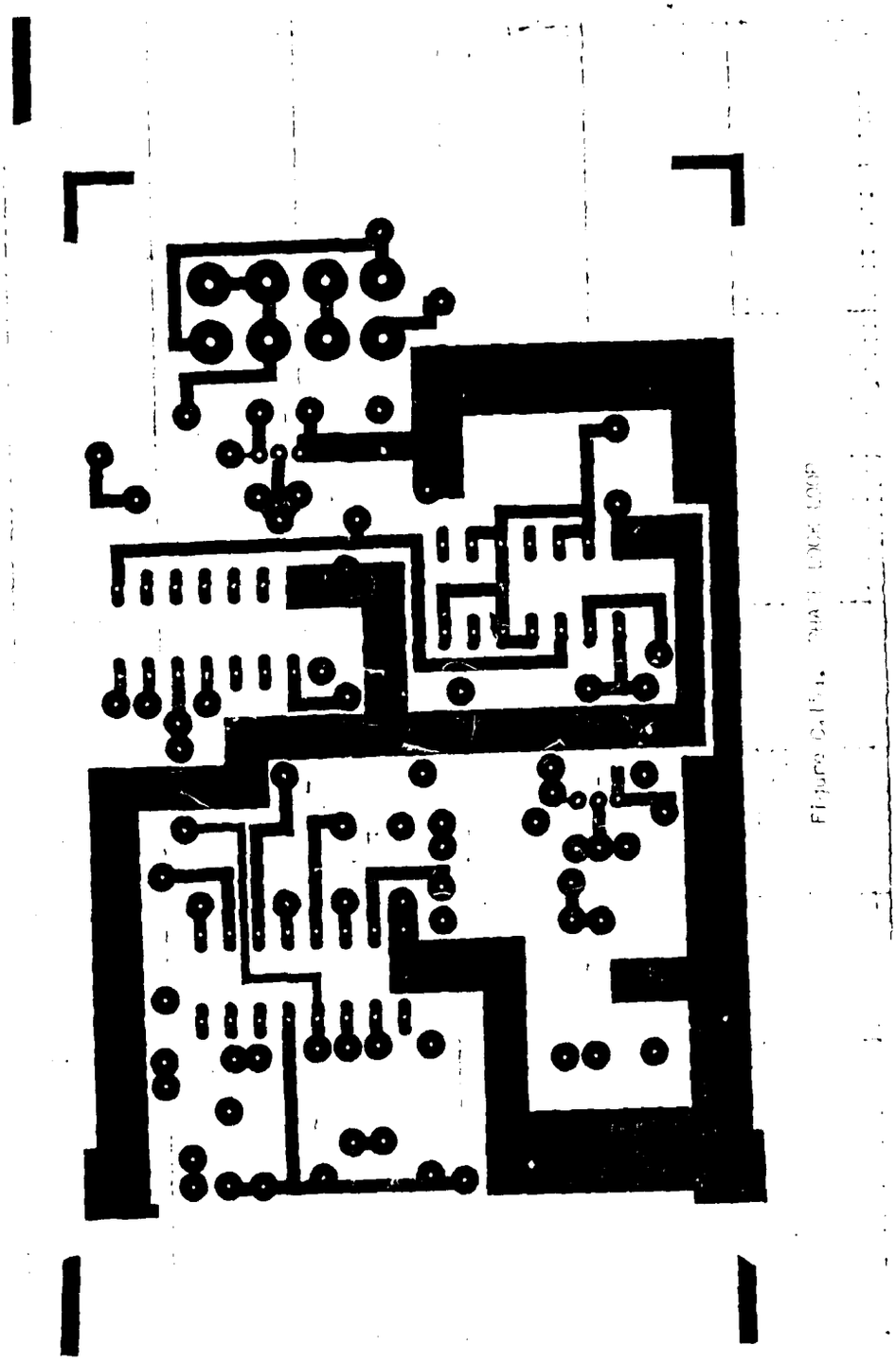


Figure C.14. 70 MHz Amplifier Output Spectrum. Full Scale = 20 dbm; Vertical Scale: 10 db/Div; Horizontal Scale: 10 MHz/Div; Center Freq. = 0 MHz.



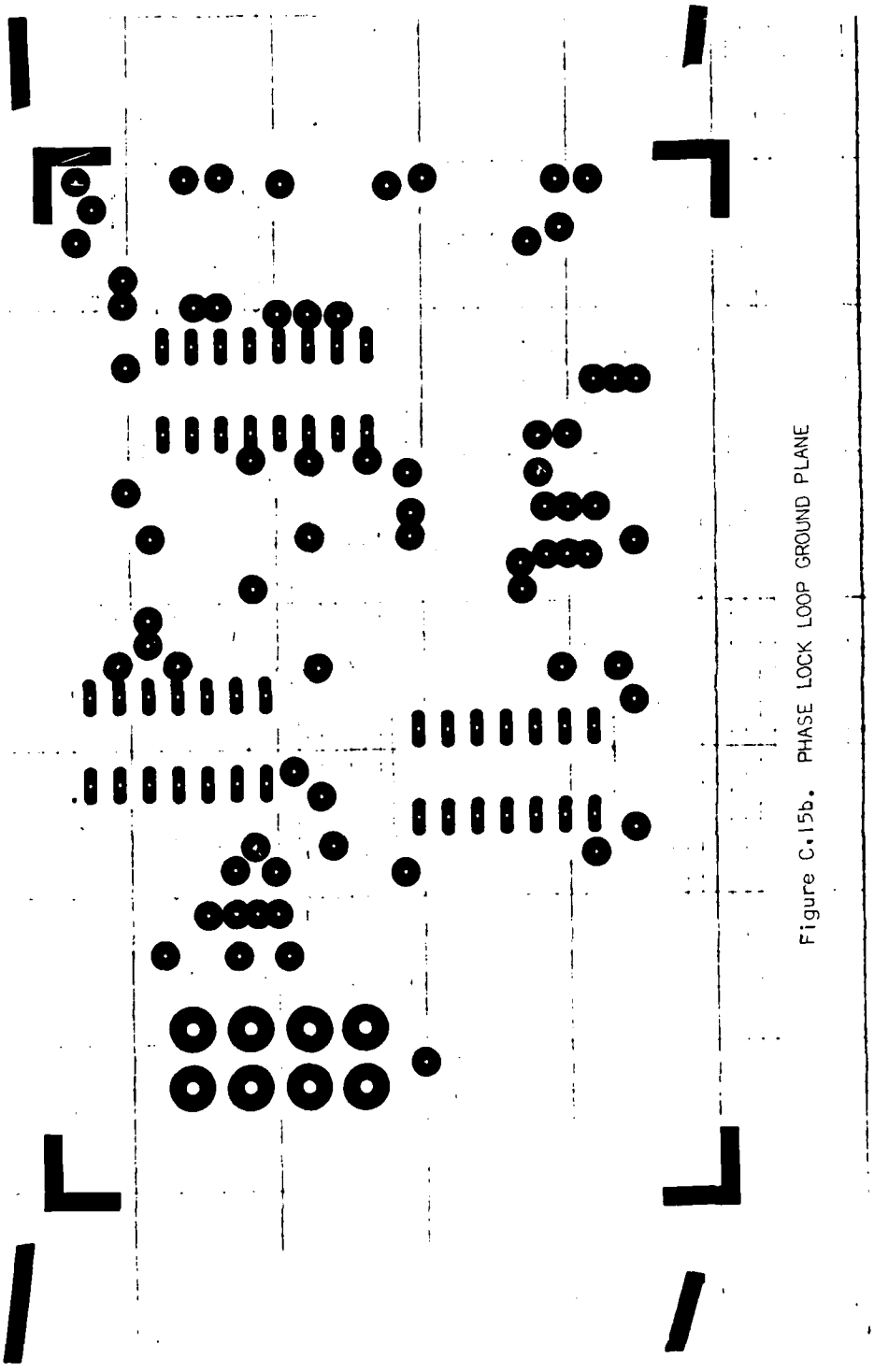


Figure C.15b. PHASE LOCK LOOP GROUND PLANE

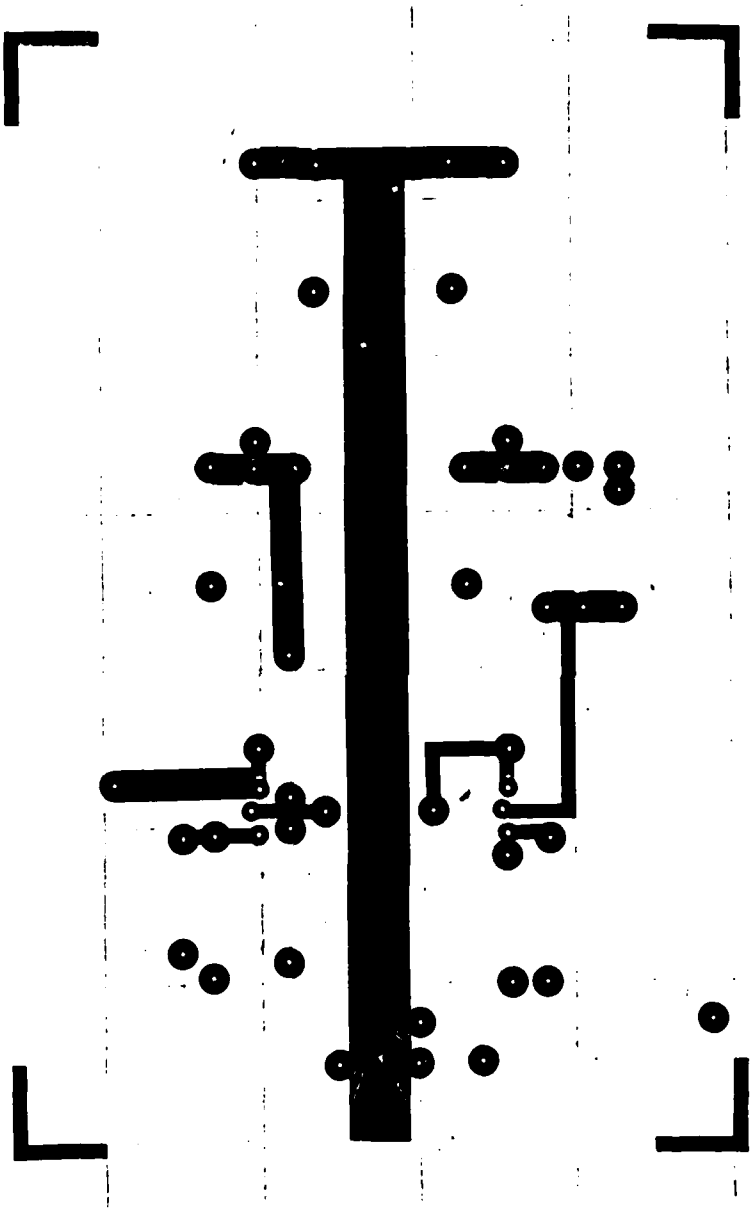


Figure C.16a. 50 MHz AMPLIFIER

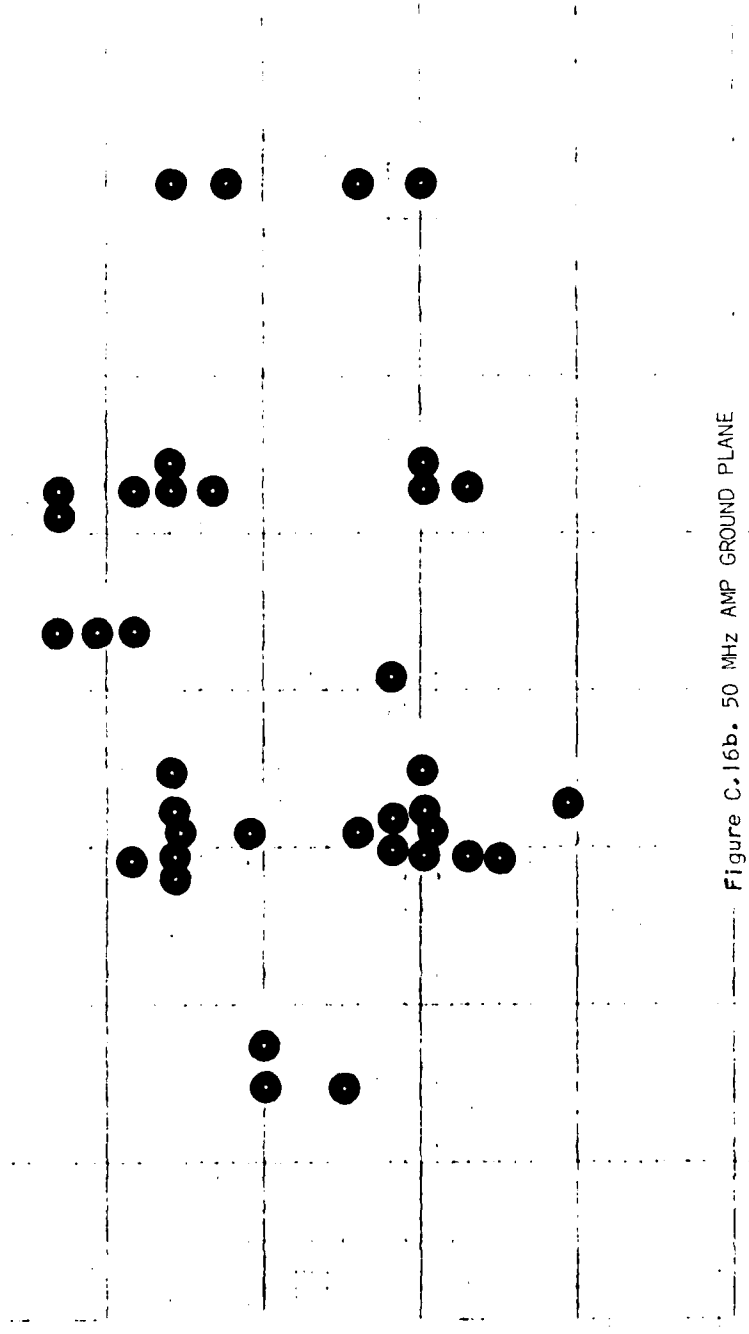


Figure C.16b. 50 MHz AMP GROUND PLANE

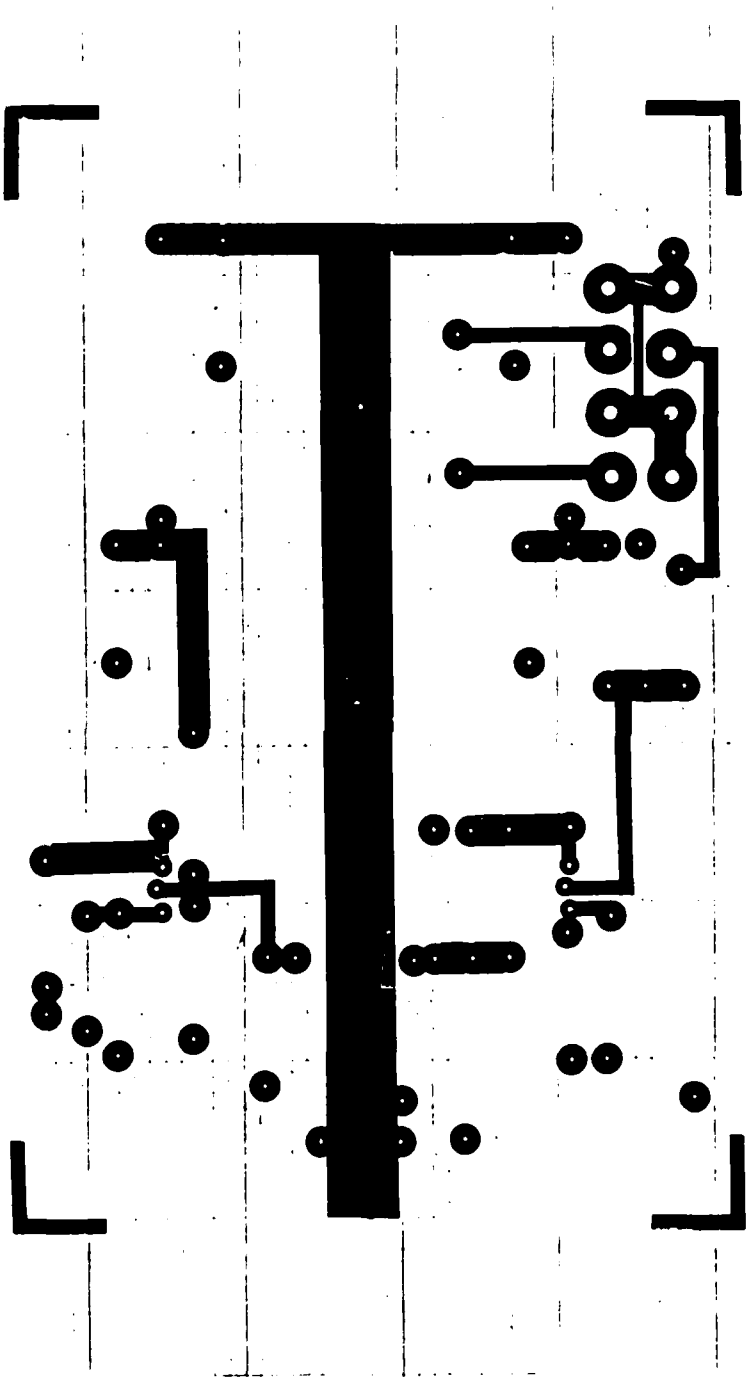


Figure C.17a. 70 MHz AMPLIFIER



Figure C.17b. 70 MHz AMP GROUND PLANE

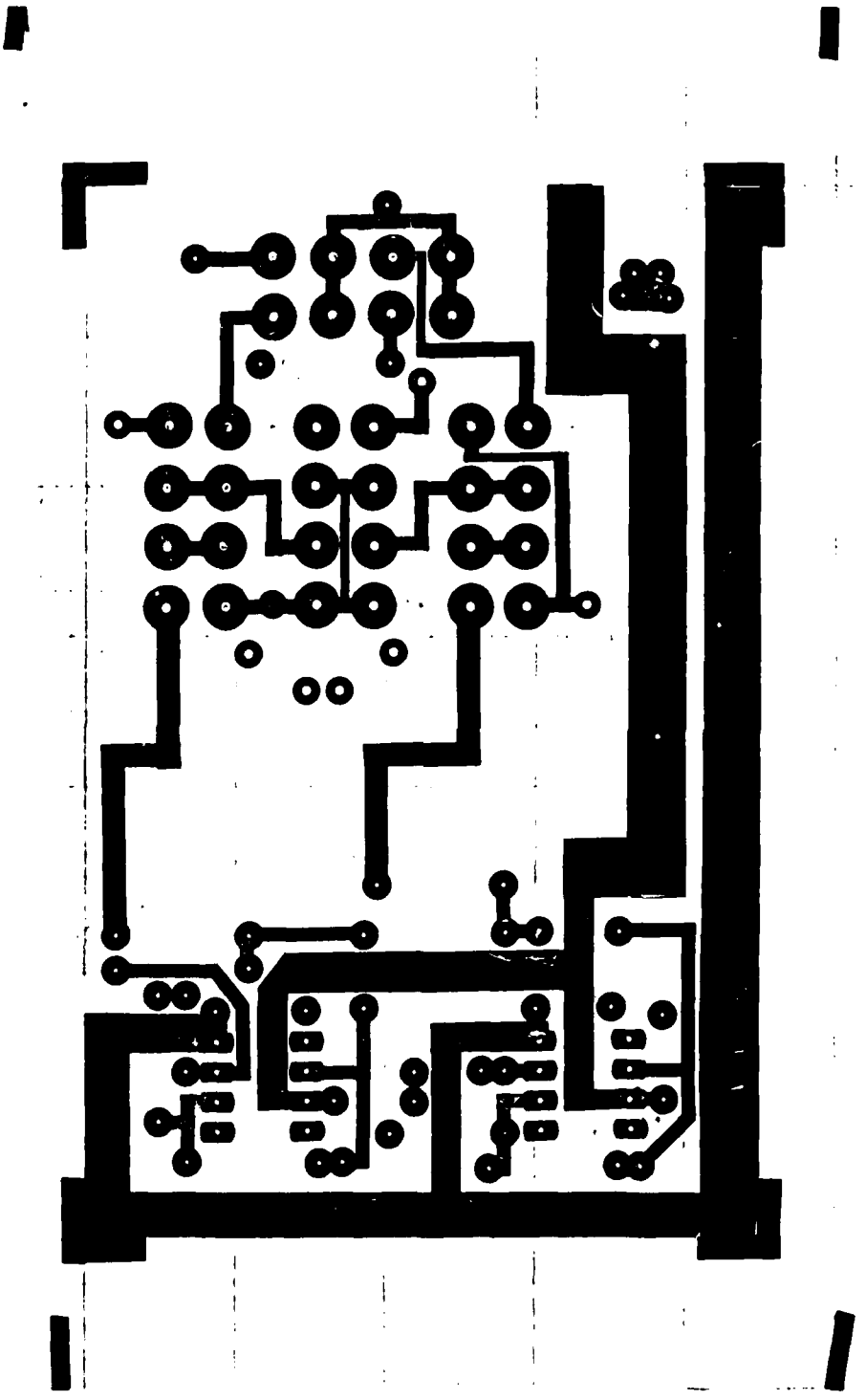


Figure C.18a. DETECTOR AND LOW-PASS FILTER

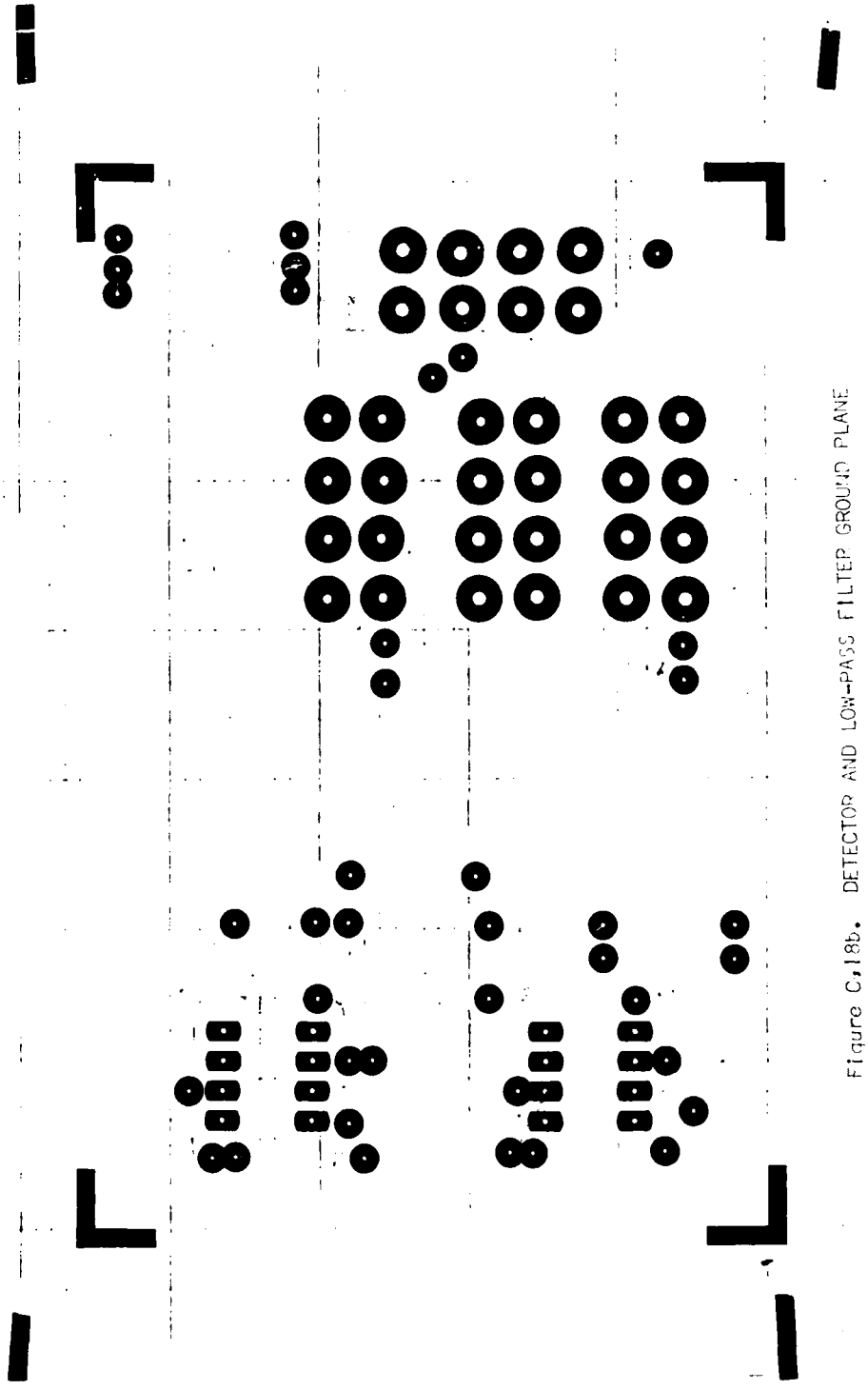


Figure C.18b. DETECTOR AND LOW-PASS FILTER GROUND PLANE

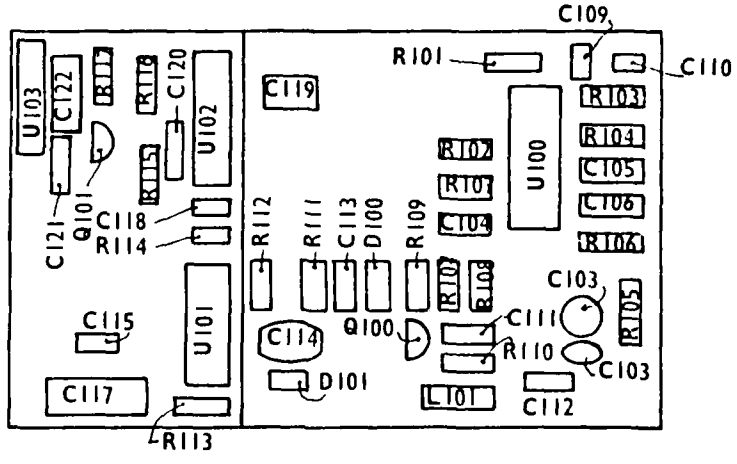


Figure C-19. 70 MHz Phase Lock Loop. The 50 MHz PLL is identical except for part numbers in the two-hundreds.

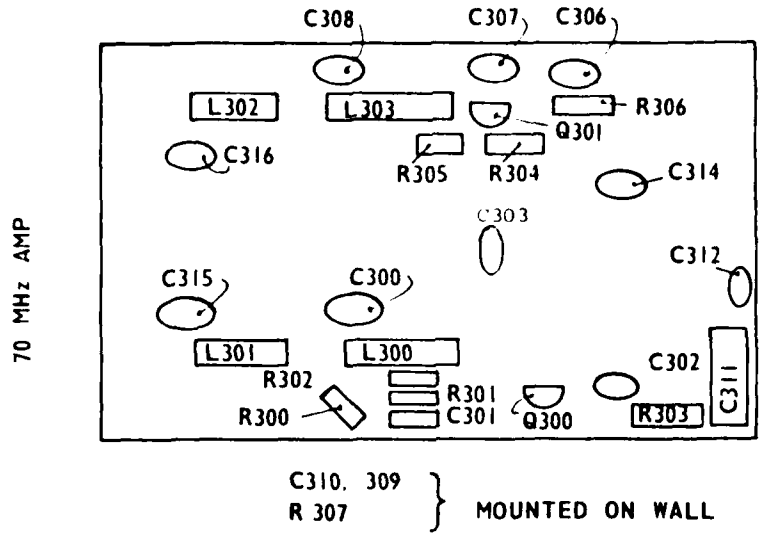


Figure C-20. 70 MHz amplifier.

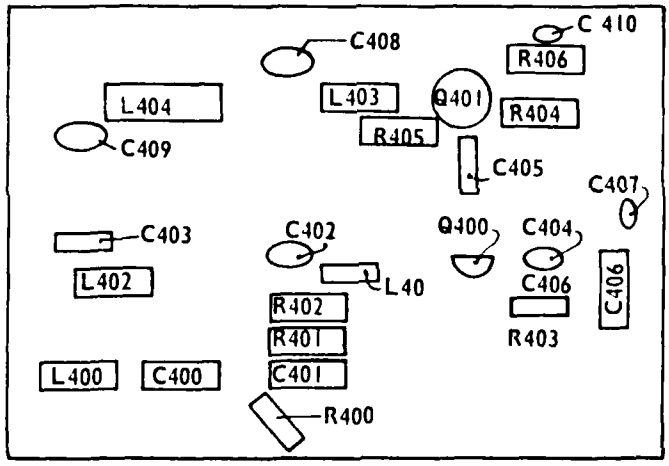


Figure C-21. 50 MHz amplifier.

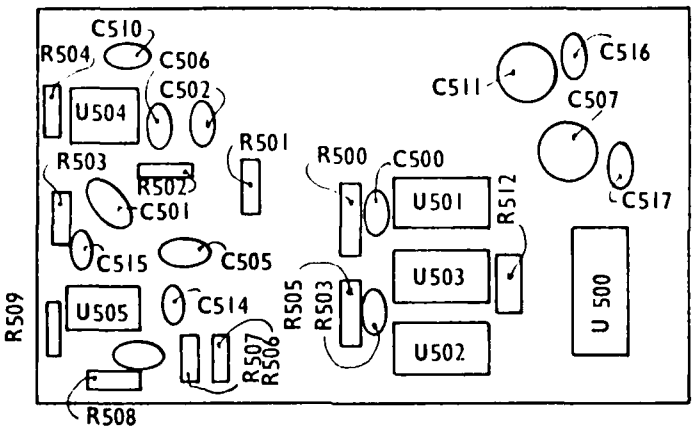


Figure C-22. Detector and Low-Pass Filter.

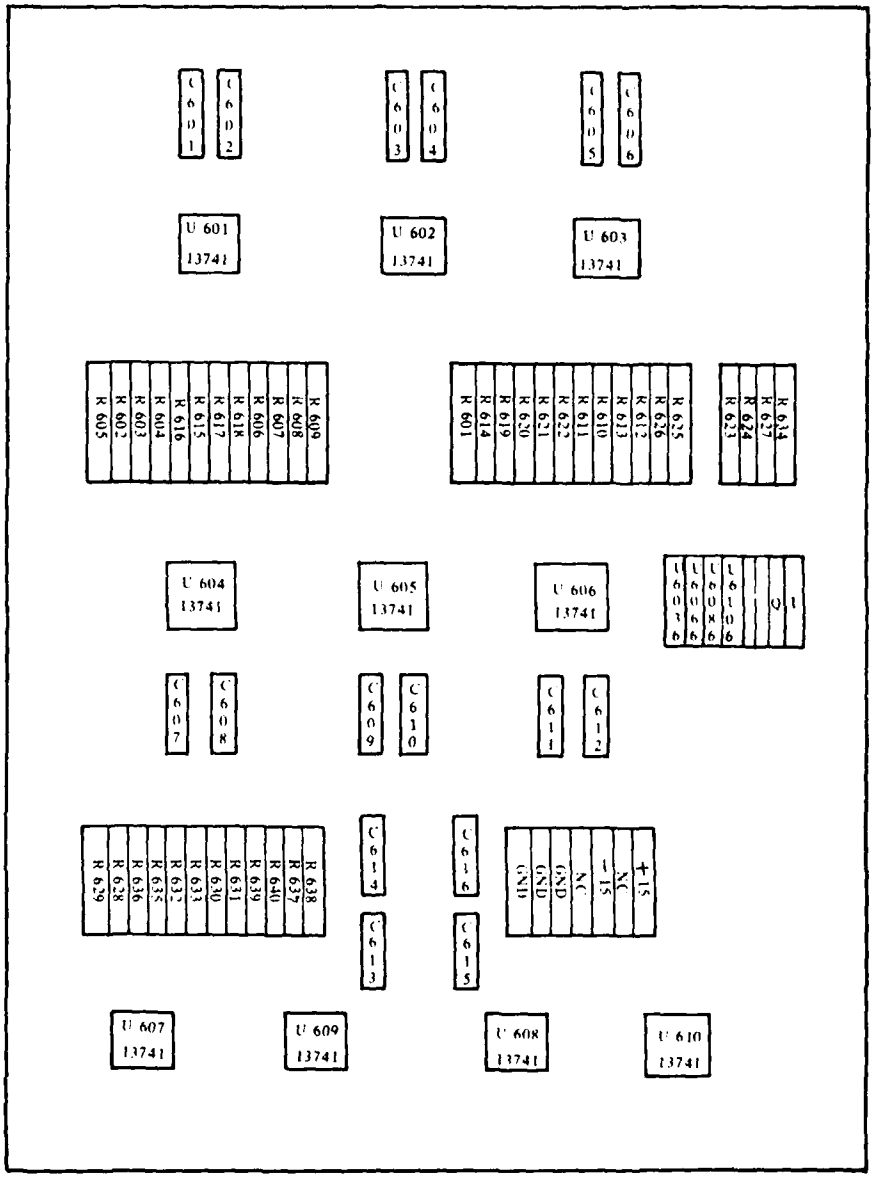


Figure C-23. Parts layout for low-pass and band-pass filter. Zener diodes are not shown.

Parts List 70 MHz PLL

Capacitors:

C100	1200 pF
C101	1200 pF Feedthrough
C102	10 microFarad, 25 Volt,Electrolytic
C103	0.01 microFarad
C104	330 pF
C105	120 pF
C106	120 pF
C107	selected
C108	1200 Feedthrough
C109	0.01 microFarad
C110	330 pF
C111	330 pF
C112	330 pF
C113	330 pF
C114	20 pF
C115	330 pF
C116	1200 pF
C117	47 microFarad, 25 Volt, Electrolytic
C118	330 pF
C119	330 pF
C120	330 pF
C121	330 pF
C122	330 pF
C123	4.7 pF

Transistors:

Q100	2N918
Q101	2N3866

Resistors: All ¼ Watt, 5%

R100	500 Ohm, 20 turn potentiometer
R101	470 Ohm
R102	2k Ohm
R103	2k Ohm
R104	2k Ohm
R105	5.1k Ohm
R106	5.1k Ohm
R107	510 Ohm
R108	20k Ohm
R109	33k Ohm
R110	18k Ohm
R111	2.2k Ohm
R112	2.7k Ohm
R113	1k Ohm
R114	1k Ohm
R115	12k Ohm
R116	47k Ohm
R117	330 Ohm

Diodes:

D100	1N4148
D101	1N4148

Inductors:

L100	4.7 microHenry
L101	4.7 microHenry
L102	4.7 microHenry

Integrated Circuits:

U100	XR215
U101	74S132
U102	93S05
U103	Mini Circuits Laboratory SRA-1 balanced mixer

Parts List 50 MHz PLL

Capacitors:

C200	1200 pF
C201	1200 pF Feedthrough
C202	10 microFarad, 25 Volt, Electrolytic
C203	0.01 microFarad
C204	330 pF
C205	120 pF
C206	120 pF
C207	selected
C208	1200 pF Feedthrough
C209	0.01 microFarad
C210	330 pF
C211	330 pF
C212	330 pF
C213	330 pF
C214	43 pF
C215	330pF
C216	1200 pF
C217	47 microfarad, 25 Volt, Electrolytic
C218	330 pF
C219	330 pF
C220	330 pF
C221	330 pF
C222	330 pF

Transistors:

Q200	2N918
Q201	2N918

Resistors: All ¼ Watt, 5%

R200	500 Ohm, 20 turn potentiometer
R201	470 Ohm
R202	2k Ohm
R203	2k Ohm
R204	2k Ohm
R205	5.1k Ohm
R206	5.1k Ohm
R207	510 Ohm
R208	20k Ohm
R209	33k Ohm
R210	18k Ohm
R211	2.2k Ohm
R212	2.7k Ohm
R213	1k Ohm
R214	1k Ohm
R215	12k Ohm
R216	47k Ohm
R217	330k Ohm

Diodes:

D200	1N4148
D201	1N4148

Inductors:

L200	4.7 microHenry
L201	4.7 microHenry
L202	4.7 microHenry

Integrated Circuits:

U200	XR215
U201	74S132
U202	93S05
U203	Mini Circuits Laboratory SRA-1 balanced mixer
U204	Mini Circuits Laboratory PSC-2 power splitter

Parts List 70 MHz Amplifier

Capacitors:

C300	1000 pF
C301	62 pF
C302	1000 pF
C303	16 pF
C305	1000 pF
C307	18 pF
C308	1000 pF
C309	1200 pF Feedthrough
C310	1200 pF
C311	47 microFarad, 25 Volt, Electrolytic
C312	0.01 microFarad
C314	12 pF
C315	1000 pF
C316	1000 pF

Resistors: All ¼ Watt, 5%

R300	100 Ohm
R301	2.2k Ohm
R302	3.9k Ohm
R303	330 Ohm
R304	2.2k Ohm
R305	2.7k Ohm
R306	330 Ohm
R307	10 Ohm

Inductors:

L300	0.28 microHenry
L301	2.2 microHenry
L302	2.2 microHenry
L303	0.28 microHenry

Transistors:

Q300	2N918
Q301	2N918

Parts List 50 MHz Amplifier

Capacitors:

C400	27 pF
C401	62 pF
C402	1000 pF
C403	1000 pF
C404	1000 pF
C405	27 pF
C406	47 microFarad, 25 Volt, Electrolytic
C407	0.01 microFarad
C408	1000 pF
C409	1000 pF
C410	1000 pF
C411	1200 pF Feedthrough
C412	1200 pF Feedthrough

Resistors: All ¼ Watt, 5%

R400	100 Ohm
R401	2.2k Ohm
R402	2.7k Ohm
R403	330 Ohm
R404	3.9k Ohm
R405	2.2k Ohm
R406	120 Ohm
R407	10 Ohm

Inductors:

L400	0.39 microHenry
L401	0.39 microHenry
L402	2.2 microHenry
L403	0.39 microHenry
L404	2.2 microHenry

Transistors:

Q400	2N918
Q401	2N3866

Parts List Detector

Capacitors:

C500	0.001 microFarad
C501	0.1 microFarad
C502	0.1 microFarad
C503	0.001 microFarad
C504	0.1 microFarad
C505	0.1 microFarad
C506	0.01 microFarad
C507	100 microFarad, 15 Volt, Electrolytic
C508	1200 pF Feedthrough
C509	1200 pF
C510	0.01 microFarad
C511	100 microFarad
C512	1200 pF Feedthrough
C513	1200 pF
C514	0.01 microFarad
C515	0.01 microFarad
C516	0.01 microFarad
C517	0.01 microFarad

Resistors: All ¼ Watt, 5%

R500	51 Ohm
R501	820 Ω
R502	1.2K Ω
R503	10k Ohm
R504	100k Ohm
R505	51 Ohm
R506	1K Ω
R507	1.2K Ω
R508	10k Ohm
R509	100k Ohm
R510	10 Ohm
R511	10 Ohm
R512	51 Ohm

Integrated Circuits:

U500	Mini Circuits	Laboratory		PSCQ2quadrature power splitter
U501	"	"	"	SRA-1 balanced mixer
U502	"	"	"	SRA-1 balanced mixer
U503	"	"	"	PSC2-1 power splitter
U504	LM741			
U505	LM741			

Parts List Low-Pass and Band-Pass Filter

1. Operational Amplifiers U601-U610 13741 (LM 741)
   U611 LM 7815 +15 volt regulator
   U612 LM 7915 -15 volt regulator

2. Capacitors C619, C620 100 microfarad, 56 volt DC

   Capacitors C601 - C618, 1 microfarad, 50 volt

3. Resistors $641, 642, 150 Ω, 10 watt

   All resistors are 1/4 watts

R601, R614, R627, R634	---	313 kΩ
R602, R605, R606, R707 R615, R616, R619, R620	---	510 kΩ
R603, R617	---	12 kΩ
R628, R635	---	15 kΩ
R604, R609, R613, R618 R622, R626, R629, R633 R636, R639	---	10 kΩ
R608, R621	---	1.5 kΩ
R610, R611, R623, R624 R630, R631, R637, R638	---	6.8 kΩ
R612, R625, R632, R640	---	5.6 kΩ

Parts List Power Supply

Capacitors:

C700	1000 microFarad, 56 Volt, Electrolytic
*C701	1000 microFarad, 56 Volt, Electrolytic
C702	1200 pF Feedthrough

Resistors:

R700	100 Ohm, 10 Watt
R701	150 Ohm, 10 Watt
*R702	200 Ohm, 5 Watt

Rectifiers:

CR700	2 Ampere, 50 Volt PIV, Diode Bridge
*CR701	2 Ampere, 50 Volt PIV, Diode Bridge

Integrated Circuits:

U700	LM7824, 24 Volt Regulator
U701	LM7812, 12 Volt Regulator
U702	LM7805, 5 Volt Regulator
*U703	LM7912, -12 Volt Regulator

T700 Power Transformer, Primary Voltage = 117 VRMS, 60 Hz
Two secondaries, 28 VRMS, 1 Ampere each
eg. Signal Transformer Co. Inc. Model 56-1

*Not required for the transmitter power supply.

Interrelations of Synthesizer Drawings and Parts Lists

Module	Schematic	Printed Board	Parts Layout	Parts List
70 MHz PPL	Fig. C.7	Fig. C.15a,b	Fig. C.19	Page C29
50 MHz PPL	Fig. C.8	Fig. C.15a,b	Fig. C.19	Page C31
70 MHz Amp	Fig. C.9	Fig. C.17a,b	Fig. C.20	Page C33
50 MHz Amp	Fig. C.10	Fig. C.16a,b	Fig. C.21	Page C34
Detector-Filter	Fig. C.11a	Fig. C.18a,b	Fig. C.22	Page C35
LP-BP Filter	Fig. C.11b	Fig. not used	Fig. C.23	Page C36
Power Supply	Fig. C.12	Fig. not used		Page C37
50 MHz Spectrum	Fig. C.13			
70 MHz Spectrum	Fig. C.14			

Appendix D

Theory of Doppler Alignment Estimators and Tropo-Channel Simulation

Contents

Part I

"Doppler Spectra as a Function of Tropo-Link Parameters and Accuracy Analysis of 'Slope' Estimators"
Interim Report for 12/11/77 to 1/11/78.....D.2

Part II

"Estimation of Quadrature Correlation Function for all Delays by Analog and Polarity-Coincidence Methods"
Interim Report for 1/11/78 to 2/11/78.....D.26

Part III

"A New Complex Gaussian Troposcatter Channel Simulator"
Interim Report for 6/11/78 to 7/11/78.....D.49

Summary of Appendix D

Part I reviews the relationship between troposcatter link geometry, the meteorology of the scattering structure, and the Doppler spectrum imparted by the mean cross-path wind. It is shown that Doppler spectrum symmetry or its lack can be used to test for correct antenna alignment. Various estimators for measures of symmetry are then discussed including average Doppler shift and skew. The variance of these estimators and their sensitivity to link parameters are calculated and tabulated for several types of signal processing.

Part II is essentially devoted to the analysis of the variance of the cross-correlation or slope estimator when one or both quadrature component signals are hard clipped. The increase in variance of 6 db due to clipping was the main reason for using non-distorted signals in the final version of the aligner.

Part III is a description of a tropochannel simulator in which delay-line tap gains are Gaussian random variables with quadrature statistics that produce Doppler effects analogous to those found in true channels. Skewed spectra can be synthesized and thus the effects of aircraft intrusion can be modeled.

Part I

Doppler Spectra as a Function of Tropo-Link Parameters and Accuracy Analysis of 'Slope' Estimators

Introduction

When a monochromatic carrier is transmitted, the received signal is normally spread about the carrier frequency because of atmospherically-induced Doppler shifts. In this chapter, the relative accuracy of the alignment scheme by 'slope method' is related to the Doppler spread function which is shown to depend on the antenna patterns and their position relative to the great-circle, the angular dependence of scattering, the cross path wind speed, and the link geometry. Next we show that the accuracy of the slope estimators is degraded by factors which increase the fade-rate such as beam-width or cross-path wind speed. Finally, we show that the accuracy is further degraded if 'hard-clipped' estimator is used instead of 'true' estimator of slope of quadrature correlation function at zero lag.

Review of Link Geometry: The paths taken by the transmitted and scattered signals are slightly bent toward the earth due to the average decrease in refractive index with height. Bean and Dutton (1966) have shown that under normal conditions the average refractivity variation near the earth's surface is linear, thereby permitting the use of an earth model whose radius is approximately 4/3 that of the true earth radius. The equivalent earth model has several distinct practical advantages: 1) the refractive index surrounding the earth is uniform and constant, 2) the curved radio paths become straight lines (or ray-paths), and 3) the ray paths have the same length as their curved counterparts. Assuming this equivalent earth model, the Doppler spectrum is written in terms of angular dependence and

antenna function using the Doppler-shift model of Birkemeier (1968).

To each point in space there corresponds a ray path length L(x,y,z) which is defined by a ray from the transmitter to the receiver passing through the given point. Surfaces of constant path or phase are approximately ellipsoids of revolution having the radio terminals as foci (Fig. 2). A signal obtained via any single moving point is shifted in frequency by an amount proportional to the rate at which the point cuts equiphase surfaces. Thus the 'single scatterer' Doppler-shift f is given by

$$f = -\frac{1}{\lambda}\frac{dL}{dt} = -\frac{1}{\lambda}\cdot v\ \nabla L \qquad (1)$$

where λ is the wavelength and v is the velocity of the moving scatterer. Using the coordinate system of Fig. 1 with origin at the midpoint of the straight (chordal) line between the terminals:

$$L = [(d+x)^2+y^2+z^2]^{\frac{1}{2}} + [(d-x)^2+y^2+z^2]^{\frac{1}{2}} \qquad (2)$$

Applying (1) and (2) yields, Birkemeier (1968),

$$f = -\frac{4}{\lambda L}\,\frac{ux(1-4d^2/L^2)+vy+wz}{1-16x^2d^2/L^4} \qquad (3)$$

where (u,v,w) are the (x,y,z) components of v. The relative importance of the various terms in (3) depends upon the position of the scatterer and on the relative magnitude of the velocity components. The along path (u) contribution is negligible because the ellipsoids are longitudinally very 'flat'. The factor $(1 - \frac{4d^2}{L^2})$ is small, and equal to $4\ z_m^2/L^2 \approx 4\ h_m^2/d^2$ where z_m and h_m are the midpath heights of an ellipsoid above the chordal axis and spherical earth, respectively. This factor ranges from 10^{-4} to 10^{-2} from the bottom to the top of the common volume. Since at a given

point, the average horizontal velocity normally greatly exceeds the average vertical velocity, Eq. (3) can be simplified to

$$f = -\frac{2}{\lambda} v\left(\frac{2y}{L}\right) = -\frac{2}{\lambda} v \sin\alpha \cong -\frac{2}{\lambda} v\alpha \qquad (4)$$

where α is the azimuthal angle of the single scatterer from the great circle. For a given crosspath wind speed, pointing the antennas to azimuthal angles away from the great circle tends to favor scatterers at larger angles α, which consequently increases the observed Doppler shift. There are many scatterers at various positions, however, that create a spectrum of Doppler shifts in the received signal. Birkemeier (1968) specified the dependence of Doppler spectrum upon azimuthal pointing angle α_a in terms of the multiplied azimuthal pattern function $G(\alpha)$ of the antennas and the scattered power per unit azimuthal angle $A(\alpha)$. For synchronously pointed antennas with boresights at α_a,

$$S(f) = S_\alpha(\alpha,\alpha_a) = G(\alpha-\alpha_a)A(\alpha) \qquad (5)$$

where $S(f)$ is the Doppler spectrum, $S_\alpha(\alpha,\alpha_a)$ is Doppler spectrum written in terms of α. And α and f are related by Eq. (4).

Composite Antenna Function

The antenna functions used in the simulation are contrived to be a simple but accurate representation of the actual antennas used in the radio experiments. The parameters of link antennas at the UW link between Arlington, Wisconsin and Cedar Rapids, Iowa and RADC link between Youngstown and Verona, New York are given in Table 1. Under normal operating conditions, the antennas are bore-sited at the horizon. Thus, rays from the lower half of the beam are directed at the foreground and are both absorbed by the

terrain and diffusely reflected. Rays from the upperhalf of each beam are directed over the horizon into the troposphere and their intersections are referred to as the common volume.

Representation of the antenna field pattern by Gaussian functions is analytically convenient and reasonably accurate. If the transmitting antenna is assumed pointed at the horizon over the great circle but the receiver antenna is azimuthally pointed at an angle α_a (azimuthal height y_a) with respect to great circle then the nominal voltage gain at the receiver from any scattering point at a given height z_o is given by

$$G_R(y)G_T(y) = \frac{1}{r_T^2} \exp\left[-\frac{y^2}{2\sigma_T^2}\right] \exp\left[-(z_o-z_{gr})^2/2\sigma_T^2\right]$$

$$\frac{1}{r_R^2} \exp\left[-\frac{(y-y_a)^2}{2\sigma_R^2}\right] \exp\left[-(z_o-z_{gr})^2/2\sigma_R^2\right] \qquad (6)$$

where $r_R \cdot r_T$ = distance to scattering point from receiving and transmitting antennas respectively.

σ_R^2, σ_T^2 = variance of Gaussian approximation determined by antenna beam width.

Within the common volume

z_{gr} = grazing ray height above link axis, and

$$\sigma_R^2 = \frac{(r_R\alpha_3)^2}{(4\ln 2)} \quad , \quad \sigma_T^2 = \frac{(r_T\alpha_3)^2}{(4\ln 2)} \quad \text{and} \quad y_a = d\alpha_a$$

where α_3 is -3db beam-width of a single antenna pattern and 2d is the length of the link axis as shown in Fig. 1.

Assuming $r_R = r_T \cong d$, at midpath and grouping the constants in Eq. (6) by $G_o(z_o,d)$, antenna function $G(\alpha)$ can be written as

$$G(\alpha) = G(y) = [G_R(y)G_T(y)]^2 = G_0^2(z_o,d)\ \exp[-\frac{y^2}{\sigma^2}]\ \exp[-\frac{(y-y_a)^2}{\sigma^2}] \qquad (7)$$

where

$$\sigma^2 = \frac{(d\alpha_3)^2}{(4\ln 2)} \quad \text{and} \quad y = d\alpha \quad \text{with } y_a = d\alpha_a \qquad (8)$$

Substituting Eq. (8) into Eq. (7), one obtains:

$$G(\alpha) = G_0^2(z_o,d)\ \exp[-\frac{\alpha^2}{\sigma_0^2}]\ \exp[-\frac{(\alpha-\alpha_a)^2}{\sigma_0^2}] \qquad (9)$$

where $\sigma_0^2 = \alpha_3^2/4\ln 2$.

In the above discussion, single Gaussian function has been used to represent the main lobe of the composite. For better refinement with side lobe structure, bi-Gaussian or penta-Gaussian function (Merrill, 1968) can be used.

Angular Dependence

A major ingredient of turbulence scattering theory is angular dependence. The signal received from a scatterer is a function of the angle between transmitted rays incident upon the scatterer and the rays from the scatterer to the receiver. The angle involved is called the "scattering angle". The reflection coefficient of the layer theories (Friis, Crawford and Hogg, 1957; Ducastel, et al., 1960) involves the same "reflection angle". Merrill (1968) called it "deflection angle" which does not explicitly indicate a particular mechanism.

A combination of turbulence theory and wave theory results in the scattering cross section

$$\sigma = \frac{C}{\lambda^{-p}} \sin^2 \beta \sin^{-p}(\theta/2) \qquad (10)$$

where θ is the scattering angle and β is the angle between the electric field vector and the ray to the receiver, β is also a function of position but is always nearly 90°. The factor C includes the effect of wavelength, scale of turbulence and mean-square refractivity fluctuation intensity. For a thin layer with homogeneous statistical properties, C is assumed to be independent of position. The power law p depends upon the particular version of turbulence theory advocated. The prominent Kolmogorov-Tatarski theory (Tatarski, 1961) gives $p = 11/3$.

Based upon the scattering cross section function of Eq. (10), one obtains the angular dependence function $A(\alpha)$

$$A(\alpha) = A(y) = Ao(\sin \theta/2)^{-11/3} \qquad (11)$$

where

$\sin \theta/2 \simeq \sqrt{\frac{z_o^2+y^2}{d^2}}$ at midpath (x=0) and Ao is a constant depending upon the wavelength and intrinsic strength of the scatterers. y and α are related as in Eq. (8). Equation (11) can be rewritten as

$$A(\alpha) = Ao(\alpha^2+z_0^2/d^2)^{-11/6} \qquad (12)$$

Frequency dependence of $A(\alpha)$ can be obtained from the relation between α and f as in Eq. (4).

Approximation of Angular Dependence for Small Antenna Pointing Angles

For small antenna pointing angles, the angular dependence function can be approximated by the Gaussian function of the form

$$A(\alpha) = A(y) = C_o \exp[-\ell_c^2 \frac{(y^2+z_o^2)}{\lambda^2 d^2}] \tag{13}$$

where C_o and ℓc are constants depending upon the 3-dimensional space correlation length. For a given thin layer at a height z_o, one can rewrite Eq. (13) as

$$A(\alpha) = A_o(z_o)\exp[-\frac{\alpha^2}{\sigma_A^2}] \tag{14}$$

where σ_A^2 specifies the severity of rolloff of $A(\alpha)$ and is dependent upon wavelength λ.

Functional Representation of Doppler Spectrum When no Clock-offset is Present

From Eqs. (5), (9) and (14) one can write the spectral density of the received signal as:

$$S(f) \equiv S(\alpha,\alpha_a) = G_o^2(z_o,d)\, Ao(z_o) \exp[-(\frac{\alpha^2}{\sigma_o^2} + \frac{(\alpha-\alpha_a)^2}{\sigma_o^2} + \frac{\alpha^2}{\sigma_A^2})]$$

$$= S_o(z_o,d) \exp[-\frac{2\alpha^2+\alpha_a^2-2\alpha\alpha_a}{\sigma_o^2} - \frac{\alpha^2}{\sigma_A^2}] \tag{15}$$

Equation (15) can be simplified by simple manipulation as:

$$S(f) = S(\alpha) = [S_o(z_o,d) \exp[-\frac{\alpha_a^2(1-k_o)}{\sigma_o^2}]] \exp[-\frac{(\alpha-k_o\alpha_a)^2}{\sigma_o^2 k_o}] \tag{16}$$

where $k_o = \frac{\sigma_A^2}{\sigma_o^2+2\sigma_A^2}$ and α and f are linearly related as in Eq. (4).

As seen from Eq. (16), the shape of the spectrum is Gaussian but shifted by an amount f_a where f_a is

$$f_a = -\frac{2}{\lambda} v\, \alpha_a \left(\frac{\sigma_A^2}{\sigma_o^2+2\sigma_A^2}\right) \tag{17}$$

This is the single scatter value, as in Eq. (4), reduced by the factor in brackets. For a given wind speed, the narrower $A(\alpha)$ is, the smaller is the slope of f_a vs α_a. The Gaussian model for $A(\alpha)$, however, yields a linear f_a vs. α_a relationship that agrees well only for small antenna pointing angles (Birkemeier, 1968).

Functional Representation of Doppler Spectrum When Clock-offset is Present

As mentioned in an earlier report that when the transmitting clock (w_c) and receiver clock (w_o) are not identical then the received Doppler spectrum gets shifted by an amount equal to clock offset Δw ($=w_c-w_o$). So if $\Delta\alpha = (\frac{\lambda}{4\pi v})\,\Delta w$, then the shifted spectrum S(f) can be obtained from Eq. (16) as

$$S(f) = S(\alpha) = S_o(z_o,d,\alpha_a)\, \exp\left[-\frac{(\alpha-\Delta\alpha-k_o\alpha_a)^2}{\sigma_o^2 k_o}\right] \tag{18}$$

where $S_o(z_o,d,\alpha_a) = S_o(z_o,d)\, \exp\left[-\left(\frac{\alpha_a^2}{\sigma_o^2}\right)\left(\frac{\sigma_o^2+\sigma_A^2}{\sigma_o^2+2\sigma_A^2}\right)\right]$

The received spectrum is still Gaussian but shifted by an amount $\bar{f}$ where $\bar{f}$ is:

$$\bar{f} = f_a + 2\pi\ \Delta\omega \tag{19}$$

Equation (18) can be written in frequency domain as:

$$S(f) = S_o(f_a, z_o, d)\ \exp[-\frac{(f-m_1)^2}{2m_2^2}] \tag{20}$$

where $m_1 = \bar{f}$, $m_2^2 = \frac{1}{2}(\frac{\sigma_o^2\sigma_A^2}{\sigma_o^2+2\sigma_A^2})](\frac{2v}{\lambda})^2$

and $S_o(f_a, z_o, d) = S_o(z_o, d)\ \exp[-(\frac{\sigma_o^2+\sigma_A^2}{\sigma_o^2+2\sigma_A^2})(\frac{\lambda}{2v})^2(\frac{f_a^2}{\sigma_o^2})]$

The resulting spectra is still Gaussian. It is well known that symmetrical Gaussian is represented by two moments of the spectrum where the first moment (m_1) gives the centroid (mean) and is defined by:

$$m_1 = \frac{\int fS(f)df}{\int S(f)df} \tag{21}$$

and the 2nd central moment (m_2) gives the variance of the spectrum and is defined by

$$m_2 = \frac{\int (f-m_1)^2 S(f)df}{\int S(f)df} \tag{22}$$

The expression of Doppler spectrum in Eq. (20) was derived based on the assumption that combined antenna pattern and angular dependence is Gaussian. This results in symmetrical Doppler spectra with mean m_1 and variance m_2. However, experimental evidence (Birkemeier, 1968) shows that the spectrum tended to be asymmetrical, when the transmitting and receiving antennas are not pointed at the great circle. At small antenna offsets from boresight, few correction terms in Gram-charlier expansion of the nearly Gaussian spectrum can account for this asymmetricity factor, e.g.,

$$S(f) = \frac{1}{\sqrt{2\pi}m_2}\exp\left(-\frac{1}{2}\left(\frac{f-m_1}{m_2}\right)^2\right)\left[1+ \frac{s_k}{3!} H_3\left(\frac{f-m_1}{m_2}\right)+\frac{Ex}{4!} H_4\left(\frac{f-m_1}{m_2}\right)+ \frac{s_k^2}{2!3!3!} H_6\left(\frac{f-m_1}{m_2}\right)\right] \quad (23)$$

Equation (23) is the corrected form of Eq. (20) such that total input power $[\int S(f)df = 1]$ is unity. In Eq. (23) s_k is defined as <u>skew coefficient</u> or <u>asymmetry coefficient</u> by:

$$s_k = \frac{m_3}{m_2^{1.5}} \quad (24)$$

where $m_3 = \left(\frac{1}{2\pi}\right)^3 \frac{(\omega-m_1)^3 S(\omega)d\omega}{\int S(\omega)d\omega}$ and is defined as <u>coefficient of excess</u>, e.g.

$$Ex = \frac{m_4}{m_2^2} - 3 \quad (25)$$

where $m_4 = \left(\frac{1}{2\pi}\right)^4 \frac{\int(\omega-m_1)^4 s(\omega)d\omega}{\int s(\omega)d\omega}$

For normal spectral slope $Ex = 0$. For other spectra having the same variance as the normal spectra, Ex will indicate whether the distribution has a flatter ($Ex<0$) or sharper ($Ex>0$) peak than the normal spectrum.

One should note that skew (s_k) and excess (Ex) can be obtained from the third (m_3) and fourth (m_4) central moments of the Doppler spectrum if non-Gaussian angular dependence (Eq. 12) is considered and thus related to tropolink parameters. In Eq. (23) $H_n(y)$ is a Hermite polynomial of degree n defined by:

$$H_n(y) = (-1)^n e^{y^2/2} \frac{d^n}{dy^n} (e^{-y^2/2}) \tag{26}$$

with $H_3(y) = y^3-3y$ and $H_4(y) = y^4-6y^2 + 3$ and $H_{n+1}(y) = y\, H_n(y)-nH_{n-1}(y)$.

Autocorrelation Function of Doppler Spectrum

The autocorrelation function $R(\tau)$ of the spectrum density (Doppler spectrum) $S(\omega)$ is defined as:

$$R(\tau) = \frac{1}{2\pi} \int_{-\infty}^{\infty} S(\omega)\, e^{j\omega\tau} d\omega \tag{27}$$

If S(f) is as given as in Eq. (23) then $R(\tau)$ can be obtained by simple manipulation as

$$R(\tau) = \left(\exp\left(jm_1\tau - \frac{m_2^2\tau^2}{2}\right)\right)\left(1 - \frac{j\, s_k m_2^3 \tau^3}{6} + \frac{(Ex) m_2^4 \tau^4}{24} - \frac{s_k^2 m_2^6}{72}\tau^6\right) \tag{28}$$

m_1, m_2, s_k, Ex are the moments of the Doppler spectrum S(f) defined earlier (Eqs. 21, 22, 24, 25).

The first and second derivatives of Eq. (28), which will later be used in alignment accuracy analysis, is given as:

$$\dot{R}(\tau) = \left(\exp\left(jm_1\tau - \frac{m_2^2\tau^2}{2}\right)\right)\left[jm_1 - m_2^2\tau - j\,\frac{s_k m_2^3}{2}\,\tau^2 + \left(\frac{m_1 s_k m_2^3}{6} + \frac{(Ex)m_2^4}{6}\right)\tau^3\right.$$

$$+ j\left(\frac{(Ex)m_2^4 m_1}{24} + \frac{s_k m_2^5}{6}\right)\cdot\tau^4 - \left(\frac{(Ex)m_2^6}{24} + \frac{s_k m_2^6}{12}\right)\tau^5$$

$$\left. - j\,\frac{m_1 s_k^2 m_2^6}{72}\,\tau^6 + \frac{s_k^2 m_2^8}{72}\,\tau^7\right] \qquad (29)$$

and $$\ddot{R}(\tau) = (-B_1 + B_2\tau^2 - B_3\tau^4 + B_4\tau^6 - B_5\tau^8) - j(c_1\tau + c_2\tau^3 - c_3\tau^5 + c_4\tau^7) \qquad (30)$$

where $$B_1 = m_1^2 + m_2^2$$

$$B_2 = m_2^4 + m_1 s_k m_2^3 + \frac{(Ex)m_2^4}{2}$$

$$B_3 = \frac{9}{24}(Ex)m_2^6 + \frac{5}{12}\,s_k^2 m_2^6 + \frac{(Ex)m_2^4 m_1^2}{24} + \frac{m_1 s_k m_2^5}{3}$$

$$B_4 = \frac{13}{72}\,s_k^2 m_2^8 + \frac{m_1^2 s_k m_2^6}{72} + \frac{(Ex)m_2^8}{24}$$

$$B_5 = \frac{s_k^2 m_2^{10}}{72}$$

$$C_1 = s_k m_2^3 + 2m_1 m_2^2$$

$$C_2 = \frac{m_1 s_k m_2^4}{3} + \frac{2 s_k m_2^5}{3} + \frac{s_k m_2^5}{2} + \frac{m_1^2 s_k m_2^3}{6}$$

$$C_3 = \frac{m_1 s_k^2 m_2^6}{6} + \frac{m_1 (Ex) m_2^6}{12} + \frac{s_k m_2^7}{6}$$

$$C_4 = \frac{m_1 s_k^2 m_2^8}{36}$$

Accuracy Analysis of the Slope Method

In the earlier report (Nov., 1977), the error analysis of the slope of the quadrature correlation function at zero lag has been shown. The formulas are summarized below for two estimators of the slope:

a) True Estimator: In this estimator, the slope (S) is estimated from the expression:

$$\hat{S} = \frac{1}{T}\int_0^T \beta(t)\,\frac{d}{dt}\,\alpha(t)dt \tag{31}$$

with $E[\hat{S}] = \dot{R}_{\alpha\beta}(0)$

where 'E' means "the expected value of" and $\alpha(t)$ and $\beta(t)$ are the quadrature components of the complex process $(\alpha(t)+j\beta(t))$ whose spectral density is given by Eq. (23). The variance of this estimator is given by:

$$\text{var}[\hat{S}] = \frac{2}{T}\int_0^T (1-\tfrac{\tau}{T})[R_{\alpha\alpha}^{\cdot\cdot}(\tau)\,R_{\beta\beta}(\tau)+[R_{\alpha\beta}^{\cdot}(\tau)]^2]d\tau \tag{32}$$

where $R_{\alpha\alpha}(\tau) = \text{Re}[R(\tau)]$ and $R_{\alpha\beta}(\tau) = \text{Im}[R(\tau)]$.

b) Estimator Hard Limiting: In this estimator, the input signals are first clipped by a 'sqn' operator $\begin{bmatrix} +1 & x(t)>0 \\ 0 & x(t)=0 \\ -1 & x(t)<0 \end{bmatrix}$, where x(t) is the input signal] and then one of the clipped signals is differentiated, e.g., the slope of the quadrature correlation function at zero lag is estimated from:

$$\hat{S}_{CL} = \frac{\pi}{2T} \int_0^T [\text{sgn } \beta(t) \frac{d}{dt} [\text{sgn}\alpha(t)]]dt$$

with
$$E[\hat{S}_{CL}] = \dot{R}_{\alpha\beta}(0) \tag{33}$$

and
$$\text{var}[\hat{S}_{CL}] = \frac{\pi^2}{4T^2} - \frac{1}{T^2} [\sin^{-1}(\rho(T))]^2 + \frac{2}{T} \int_0^T (1 - \frac{\tau}{T}) \frac{\dot{\gamma}^2(0)[\gamma^2+\rho^2]+\dot{\rho}^2+\dot{\gamma}^2+2\dot{\gamma}(0)[\dot{\rho}\gamma-\rho\dot{\gamma}]}{1-\rho^2-\gamma^2} d\tau \tag{34}$$

where $\rho(\tau) = \text{Re}[\frac{R(\tau)}{R(0)}]$ and $\gamma(\tau) = \text{Im}[\frac{R(\tau)}{R(0)}]$

where 'Re' implies 'Real' and 'Im' implies 'Imaginary'.

Equations 28, 29 and 30 were substituted in Eqs. (32) and (34) and the variance is compared for both estimators with different spectral moments (m_1, m_2, m_3 and m_4 is assumed zero for simplicity). The results are summarized below:

Effect of Fade Rate on Skew: As mentioned before, the spectral moments are functions of tropolink parameters such as wind speed, antenna beam width, angular dependence, transmitted frequency, the distance between the transmitter and the receiver etc. The antenna elevation angle is assumed zero. The variations in the link parameters causes these coupled spectral moments to change accordingly. So, simply varying these moments will mimic the different link conditions, the net effect of which will result in changed moments. In table 2, with $m_1 = 0$, the effect of fade rate under different 'skew' (asymmetric) conditions is shown. Although with different 'skew' conditions, m_1 should correspondingly be non-zero, but in calculations

first m_1 is assumed zero (Table 2) and then for a given m_2, m_1 is varied (Table 3). For a given skew coefficient, the difference in m_1 can account for the 'residual' clock-offset (see Eq. 19). From Table 2, it could be observed that the variance of both estimators increases in proportion to the spectral width. If the spectral width (or the fade rate) increases by a factor of 2, the variance also increases by the same factor. The theoretical explanation is given in Appendix 1. The clipping loss (defined as the ratio of $\frac{\text{variance of true estimator of slope}}{\text{variance of clipped estimator of slope}}$) is in the range of -4 to -5 db. If the large amount of clock-offset is present, then the clipping loss decreases accordingly (see Table 3). If the Doppler spectrum is symmetrical ($m_3 = 0$), then it is shown in Table 4 that for large clock-offset (as m_1 increases) the clipping loss could result in clipping gain.

Path	UW Link	RADC Link
Antenna parameters	Symmetrical, 28' steerable diameter paraboloids with circular nominal -3 db bandwidth of 2.8°, 0° elevation σ_o^2=2.82 (degree^2)	Symmetrical, 28' steerable diameter paraboloids with circular nominal -3 db bandwidth of .54°,0° elevation σ_o^2=.105 (degree^2)
Path length (2d)	231 km	168 miles, 268.80 km
Frequency, wavelength	810 MHz, .37 m	4.86 GHz, .0625 m
Size of common volume (2Lx*2Ly*Lz) (lengths in km)	110.*5.6*2.8	34.9*1.26*.63
Z_{gr} grazing ray height from link axis	1.57 km	2.12 km
Z_c, height of earth surface from link-axis	.78 km	1.06 km
Zup, height of upper beam from link axis	4.39 km	2.75 km
Z_b, height of the intersection of the transmitter upper beam and receiver from link axis	2.31 km	2.40 km
Z_o', single layer height assumed from link axis	2.5 km	2.5 km
σ_A^2, variance (degree^2) of Gaussian angular dependence for fade rate (m_2) of 2,4,6,8 & 10 Hz and wind speed 2.5 m/sec	.045,.2,.547,1.394 4.905	.001,.005,.014,.032,.077 (and .135 for m_2=11 Hz)
θ, angle of antenna central beam to the link axis	1.55°	1.81°

Table D.1

Link Parameters for UW and RADC Links

Table 2

Comparison of Two Estimators of Slope at Different Fade Rates and Antenna Misaligned Positions (m_1=0, Ex=0, T=5).

S_k, skew coefficient	VARTR variance of true estimator			VARCLP variance of clipped estimator			LOSS (VARTR/VARCLP)			DB LOSS 10 $\log_{10}$ (Loss)		
	m_2=.5	1.0	2.0	.5	1.0	2.0	.5	1.0	2.0	.5	1.0	2.0
-.50	.0751	.1615	.3507	.2697	.5126	.9986	.2784	.3151	.3512	-5.5540	-5.0160	-4.5447
-.40	.0770	.1617	.3451	.2678	.5065	.9840	.2875	.3192	.3507	-5.4133	-4.9588	-4.5501
-.30	.0793	.1636	.3431	.2663	.5018	.9728	.2980	.3259	.3526	-5.2586	-4.8686	-4.5267
-.25	.0807	.1651	.3432	.2657	.5000	.9685	.3036	.3301	.3544	-5.1772	-4.8133	-4.5054
-.20	.0821	.1669	.3441	.2652	.4985	.9650	.3095	.3348	.3566	-5.0938	-4.7523	-4.4782
-.15	.0836	.1690	.3457	.2648	.4974	.9623	.3156	.3399	.3593	-5.0088	-4.6066	-4.4459
-.10	.0852	.1715	.3480	.2646	.4965	.9603	.3219	.3454	.3623	-4.9227	-4.6169	-4.4089
0	.0886	.1772	.3543	.2644	.4959	.9588	.3351	.3573	.3696	-4.7489	-4.4691	-4.3232
.1	.0923	.1838	.3630	.2646	.4965	.9603	.3487	.3702	.3779	-4.5754	-4.3152	-4.2258
.15	.0942	.1875	.3680	.2648	.4974	.9623	.3557	.3769	.3825	-4.4896	-4.2376	-4.1740
.20	.0962	.1913	.3736	.2652	.4985	.9650	.3627	.3837	.3872	-4.4049	-4.1606	-4.1208
.25	.0982	.1952	.3797	.2657	.5000	.9685	.3697	.3904	.3920	-4.3216	-4.0845	-4.0667
.30	.1003	.1993	.3862	.2663	.5018	.9728	.3767	.3972	.3970	-4.2398	-4.0100	-4.0121
.40	.1046	.2079	.4006	.2678	.5065	.9840	.3907	.4105	.4071	-4.0820	-3.8672	-3.9030
.50	.1090	.2169	.4166	.2697	.5126	.9986	.4043	.4231	.4172	-3.9331	-3.7352	-3.7963

Table 3

Effect of non-zero m_1 in comparing the performance of two estimators of slope at a given fade rate and different antenna misaligned positions for m_2=1, Ex=0 and T=5.

S_k, skew coefficient	VARTR variance of true estimator			VARCLP variance of clipped estimator			LOSS (VARTR/VARCLP)			DB LOSS 10 $\log_{10}$ (Loss)		
	m_1=0	.1	.3	0	.1	.3	0	.1	.3	0	.1	.3
-.50	.1615	.1767	.2257	.5126	.5126	.5126	.3151	.3446	.4403	-5.0160	-4.6263	-3.5626
-.40	.1617	.1743	.2185	.5065	.5065	.5065	.3192	.3440	.4315	-4.9588	-4.6339	-3.6500
-.30	.1636	.1736	.2131	.5018	.5018	.5018	.3259	.3460	.4246	-4.8686	-4.6098	-3.7200
-.25	.1651	.1739	.2109	.5000	.5000	.5000	.3301	.3478	.4219	-4.8133	-4.5871	-3.7479
-.20	.1669	.1745	.2092	.4985	.4985	.4985	.3348	.3501	.4196	-4.7523	-4.5592	-3.7715
-.15	.1690	.1775	.2078	.4974	.4974	.4974	.3399	.3529	.4177	-4.6866	-4.5236	-3.7408
-.10	.1715	.1768	.2067	.4965	.4965	.4965	.3454	.3561	.4163	-4.6169	-4.4840	-3.8062
0	.1772	.1803	.2055	.4959	.4959	.4959	.3573	.3637	.4144	-4.4691	-4.3927	-3.8257
.10	.1838	.1849	.2055	.4965	.4955	.4965	.3702	.3724	.4138	-4.3152	-4.2894	-3.8318
.15	.1875	.1876	.2059	.4974	.4974	.4974	.3769	.3772	.4140	-4.2376	-4.2348	-3.8304
.20	.1913	.1904	.2065	.4985	.4985	.4985	.3837	.3820	.4143	-4.1606	-4.1790	-3.8265
.25	.1952	.1935	.2075	.5000	.5000	.5000	.3904	.3870	.4149	-4.0845	-4,1226	-3.8202
.30	.1993	.1968	.2086	.5018	.5018	.5018	.3972	.3921	.4157	-4.0100	-4.0661	-3.8119
.40	.2079	.2038	.2116	.5065	.5065	.5065	.4105	.4023	.4178	-3.8672	-3.9566	-3.7900
.50	.2169	.2114	.2155	.5126	.5126	.5126	.4231	.4123	.4205	-3.7352	-3.8477	-3.7601

Table 4

Comparison of two estimators of slope of quadrature correlation at zero lag (or center frequency of symmetrical doppler spectrum) with varying clock offset and antenna positions (S_k=0, Ex=0, T=5)

fade rate m_2, spectral width	VARTR variance of true estimator				VARCLP variance of clipped estimator				LOSS = VARTR/VARCLP				DB LOSS = 10 $\log_{10}$ (Loss)			
	m_1=0	.1	.3	.5	0	.1	.3	.5	0	.1	.3	.5	0	.1	.3	.5
.1	.0092	.0260	.1266	.2604	.0617	.0771	.1083	.0838	.1494	.3371	1.1690	3.1070	-8.2556	-4.7228	.6702	4.9234
.2	.0299	.0419	.1220	.2505	.1186	.1230	.1355	.1253	.2519	.3404	.9006	1.9995	-5.9881	-4.6795	-.4545	3.0092
.3	.0514	.0598	.1225	.2389	.1699	.1709	.1743	.1715	.3023	.3497	.7031	1.3926	-5.1952	-4.5632	-1.5301	1.4384
.4	.0706	.0771	.1286	.2300	.2178	.2179	.2185	.2180	.3240	.3537	.585	1.0547	-4.8944	-4.5132	-2.3028	0.2316
.5	.0886	.0941	.1381	.2258	.2644	.2644	.2644	.2644	.3351	.3559	.5221	.8542	-4.7489	-4.4872	-2.8228	-.6846
1.0	.1772	.1803	.2055	.2558	.4959	.4959	.4959	.4959	.3573	.3637	.4144	.5159	-4.4691	-4.3927	-3.8257	-2.8747
1.5	.2658	.2680	.2854	.3204	.7274	.7274	.7274	.7274	.3654	.3684	.3929	.4405	-4.3723	-4.3367	-4.0623	-3.5606
2.0	.3543	.3560	.3694	.3961	.9588	.9588	.9588	.9588	.3696	.3713	.3852	.4131	-4.3232	-4.3028	-4.1426	-3.8390
2.5	.4429	.4442	.4550	.4767	1.1902	1.1902	1.1902	1.1902	.3721	.3732	.3823	.4005	-4.2936	-4.2804	-4.1758	-3.9729
3.0	.5314	.5325	.5416	.5598	1.4216	1.4216	1.4216	1.4216	.3738	.3746	.3810	.3938	-4.2739	-4.2645	-4.1911	-4.0477
4.0	.7083	.7092	.7161	.7299	1.8844	1.1844	1.8844	1.8844	.3759	.3764	.3800	.3873	-4.2493	-4.2440	-4.2020	-4.1193

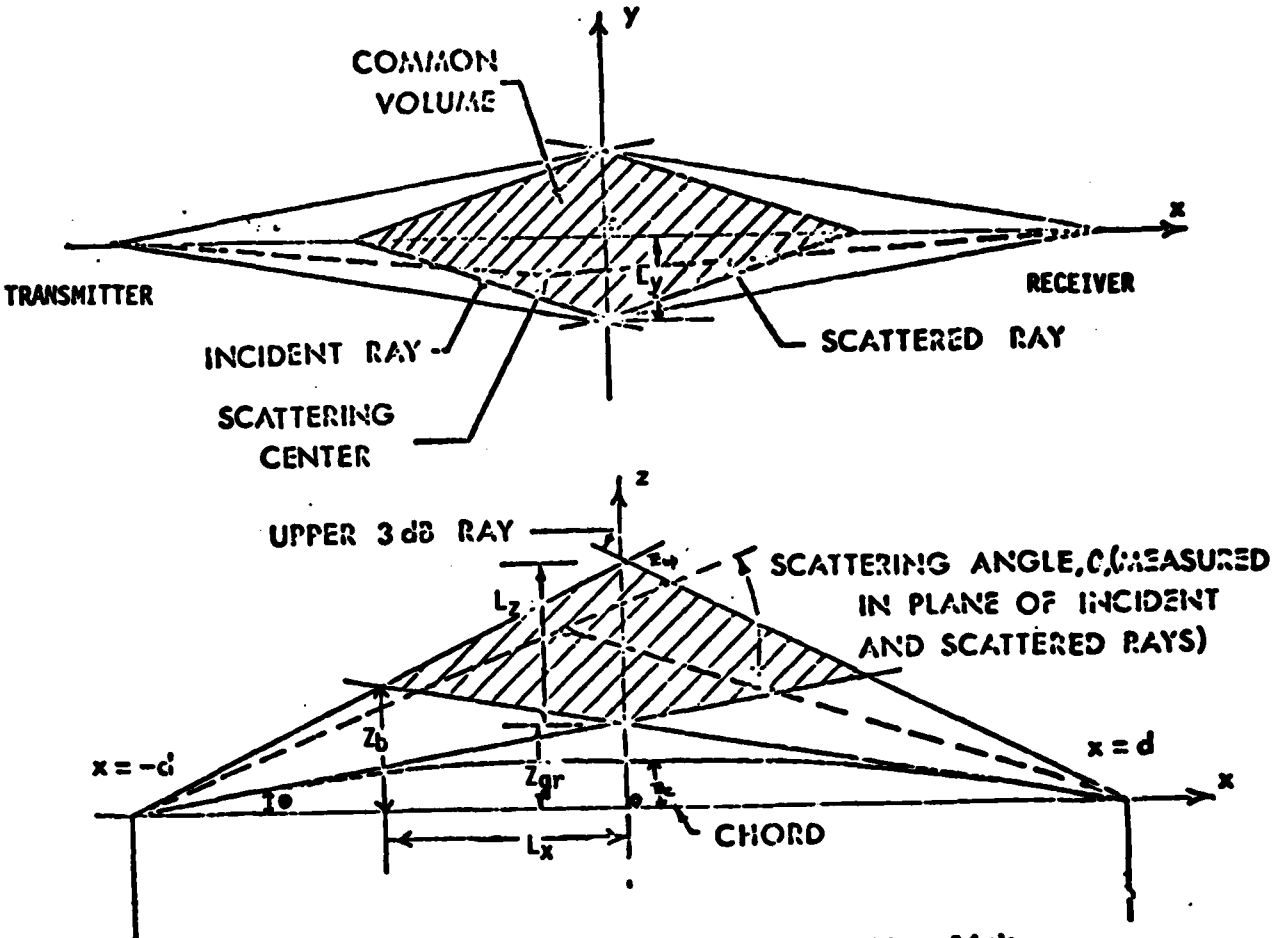


Figure 1 Plan and elevation views of troposcatter link

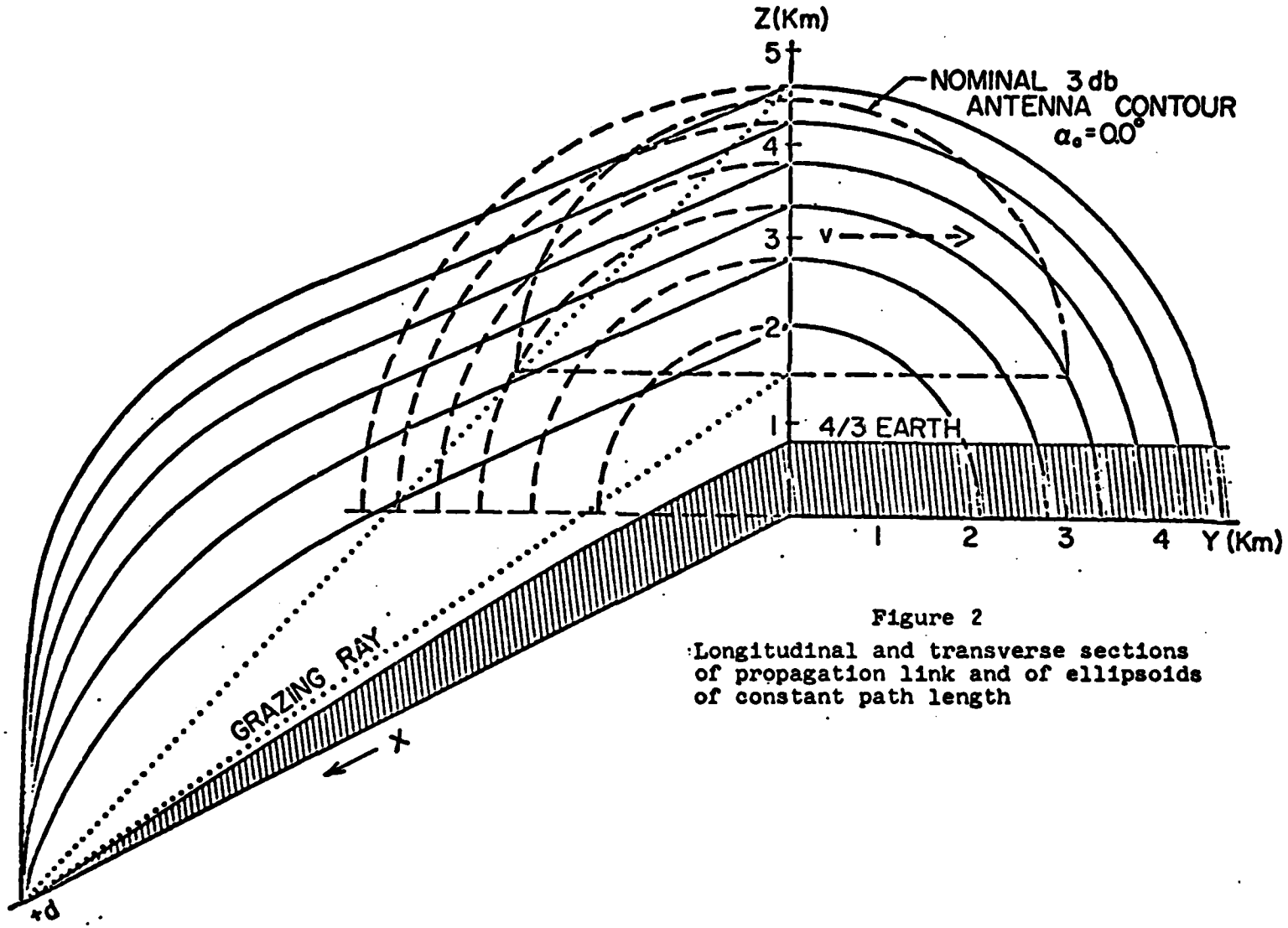


Figure 2

Longitudinal and transverse sections of propagation link and of ellipsoids of constant path length

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Appendix A1

In this appendix the effect of the change in the width of the Doppler spectrum on the variance of the two estimators of the slope of the quadrature correlation function at zero lag is considered. Since the variance is inversely proportional to the averaging time and the spectral width is an indicator of fade rate, so the effect of the different fade rates (due to different wind velocity, antenna patterns, etc.) on the required averaging time is estimated by assuming that the total received power is the same under various fading conditions, e.g., if the Doppler spectrum increases in width by a factor of k, then

$$R_{\alpha\beta}(\tau) \rightarrow R_{\alpha\beta}(k\tau)$$

and (A1-1)

$$R_{\alpha\alpha}(\tau) \rightarrow R_{\alpha\alpha}(k\tau)$$

where $R_{\alpha\beta}(\tau)$ is the quadrature cross-correlation function and $R_{\alpha\alpha}(\tau)$ is the quadrature auto-correlation function of quadrature processes $\alpha(t)$ and $\beta(t)$. In deriving Eq. (A1-1), the well-known Fourier transform scaling relationship is utilized, e.g.

$$\frac{1}{a} F(\frac{\omega}{a}) \leftrightarrow f(a\tau)$$

Substituting Eq. (A-1) in equations (32) and (34), one obtains

$$\text{var}[\hat{S}] = \frac{2k}{T} \int_0^T (1 - \frac{\eta}{kT})[R_{\alpha\alpha}(\eta)R_{\beta\beta}(\eta)+[R_{\alpha\beta}(\eta)]^2]d\eta \qquad \text{(A1-2)}$$

and

$$\text{var}[\hat{S}_{CL}] = \frac{\pi^2}{4T^2} - \frac{1}{T^2}[\sin^{-1}(\rho(T))]^2 \qquad \text{(A1-3)}$$

$$+ \frac{2k}{T}\int_0^T (1 - \frac{\eta}{kT})(\frac{\dot{\gamma}^2(0)(\gamma^2+\rho^2)+\dot{\rho}^2+\dot{\gamma}^2+2\dot{\gamma}(0)[\dot{\rho}\gamma-\rho\dot{\gamma}]}{1-\gamma^2-\rho^2}\, d\eta)$$

For large 'T', Eq. (A1-2) and (A1-3) reduce to

$$\text{Var}[\hat{S}] = \frac{2k}{T}\int_0^T [R_{\alpha\alpha}^{\cdot\cdot}(\eta)R_{\beta\beta}(\eta)+[R_{\alpha\beta}^{\cdot}(\eta)]^2]d\eta$$

and (A1-4)

$$\text{Var}[\hat{S}_{CL}] = \frac{2k}{T}\int_0^T \frac{\dot{\gamma}^2(0)(\gamma^2+\rho^2)+\dot{\rho}^2+\dot{\gamma}^2+ 2\dot{\gamma}(0)[\dot{\rho}\gamma-\rho\dot{\gamma}]}{1-\rho^2-\gamma^2}\, d\eta$$

For Eq. (A1-4) it is evident that the variance of both estimators increase by the same factor as the width of the Doppler spectrum. In *other words*, an increase in the width of the Doppler spectrum requires the increase in the averaging time by the same factor.

Estimation of Quadrature Correlation Function for all Delays by Analog and Polarity-Coincidence Method:

In the report (9/11/77-10/11/77), the expected value and the variance of the estimator of the quadrature correlation function by analog method have been derived which are summarized below.

If $\alpha(t)$ and $\beta(t)$ are the quadrature processes of unit power then the quadrature correlation function $R_{\alpha\beta}(\tau)$ is estimated by:

$$\hat{R}_{\alpha\beta}(\tau) = \frac{1}{T}\int_0^T \alpha(t)\beta(t-\tau)dt \tag{1}$$

the expected value and variance of $\hat{R}_{\alpha\beta}(\tau)$ is given by:

$$E[\hat{R}_{\alpha\beta}(\tau)] = R_{\alpha\beta}(\tau) \tag{2}$$

and

$$\text{var}[\hat{R}_{\alpha\beta}(\tau)] = \frac{1}{T}\int_{-T}^{T} (1-\frac{|n|}{T}) [R^2_{\alpha\alpha}(n)+R_{\alpha\beta}(n+\tau)R_{\beta\alpha}(n-\tau)]dn \tag{3}$$

For τ=0, zero delay (lag), Eq. (2) and (3) reduce to:

$$E[\hat{R}_{\alpha\beta}(0)] = 0 \tag{4}$$

and

$$\text{var}[\hat{R}_{\alpha\beta}(0)] = \frac{1}{T}\int_{-T}^{T} (1-\frac{|n|}{T}) [R^2_{\alpha\alpha}(n)-R^2_{\alpha\beta}(n)]dn \tag{5}$$

In the same report, the quadrature correlation function is estimated by the polarity-coincidence method as

$$\hat{r}_c(\tau) = \frac{1}{T}\int_0^T \text{sgn}[\alpha(t)]\text{sgn}[\beta(t-\tau)]dt \tag{6}$$

where sgn is the 'hard-clipped' operator, defined as

$$\text{sgn}(x) = \begin{cases} 1 & x > 0 \\ 0 & x = 0 \\ -1 & x < 0 \end{cases}$$

the expected value of $\hat{r}_c(\tau)$ is given by Van Vleck [1966], e.g.

$$E[\hat{r}_c(\tau)] = \frac{2}{\pi} \text{ arc } \sin(R_{\alpha\beta}(\tau)) \tag{7}$$

In the above mentioned report, the variance of $\hat{r}_c(0)$ had been derived as

$$\text{Var}[\hat{r}_c(0)] = \frac{4}{\pi^2 T} \int_{-T}^{T} [\{\text{arc } \sin\rho(n)\}^2 - \{\text{arc } \sin r(n)\}^2] dn \tag{8}$$

In Eq. (8), $\rho(n)$ is the autocorrelation function of in-phase or quadrature processes and $r(n)$ is the normalized quadrature correlation function given by Eq. (1).

In this report, the variance of the estimator of the polarity-coincidence quadrature correlation function is computed for all delays and the two estimators of correlation function are compared on the basis of signal to noise ratio (SNR). If SNR is defined as

$$\text{SNR} = \frac{(\text{DC output of the correlation at a given lag})^2}{(\text{variance of the output at that lag})} \tag{9}$$

then clipping loss or gain [Cheng, 1968] is defined as

$$\frac{(\text{SNR of polarity coincidence estimator})}{(\text{SNR of analog estimator})} \tag{10}$$

Variance of Polarity Coincidence Quadrature Correlator

In this correlator, the quadrature correlation function ($r_c(\tau)$) is estimated by Eq. (6). The variance of this estimator is given by:

$$\mathrm{Var}[\hat{r}_c(\tau)] = \frac{1}{T^2}\int_0^T\int_0^T E[\mathrm{sgn}\alpha(u)\mathrm{sgn}\alpha(v)\mathrm{sgn}\alpha(u-\tau)\mathrm{sgn}\beta(v-\tau)]\,du\,dv - E^2[\hat{r}_c(\tau)] \qquad (11)$$

In Eq. (11), one needs to obtain fourth product moment [McFadden, 1958]:

$$E[\mathrm{sgn}\alpha(u)\mathrm{sgn}\alpha(v)\mathrm{sgn}\beta(u-\tau)\mathrm{sgn}\beta(v-\tau)],$$

where α and β are jointly gaussian with zero mean and equal variance (σ).

To evaluate this equation, we write:

$$y_1 = \mathrm{sgn}\alpha(u)$$

$$y_2 = \mathrm{sgn}\beta(u-\tau)$$

$$y_3 = \mathrm{sgn}\alpha(v)$$

$$y_4 = \mathrm{sgn}\beta(v-\tau)$$

and

$$P_4 = P[\alpha(u) \geq 0,\ \beta(u-\tau) \geq 0,\ \alpha(u) \geq 0,\ \beta(v-\tau) \geq 0] \quad .$$

Then it is known that, for example, [McFadden, 1966] and [Childs, 1967] that

$$P_4 = \frac{1}{16}\left[1 + \sum_{j>i\geq 1}^{4} E[y_2 y_j] + E[y_1 y_2 y_3 y_4]\right] \qquad (12)$$

The problem now is to evaluate P_4. To do this, we let

$$z_1 = \alpha(u)/\sigma$$

$$z_2 = \beta(u-\tau)/\sigma$$

$$z_3 = \alpha(v)/\sigma$$

$$z_4 = \beta(v-\tau)/\sigma$$

Then one can obtain (see report 9/11/77-10/11/77) the covariance matrix (C) of the Gaussian variables z_1, z_2, z_3, z_4 with zero mean and unit variance.

If $\eta = u-v$, then

$$C = \begin{vmatrix} 1 & r(\tau) & \rho(n) & r(n+\tau) \\ r(\tau) & 1 & r(\tau-n) & \rho(n) \\ \rho(n) & r(\tau-n) & 1 & r(\tau) \\ r(n+\tau) & \rho(n) & r(\tau) & 1 \end{vmatrix}$$

$$= \begin{vmatrix} \rho_{11} & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{12} & \rho_{22} & \rho_{23} & \rho_{24} \\ \rho_{13} & \rho_{23} & \rho_{33} & \rho_{34} \\ \rho_{14} & \rho_{24} & \rho_{34} & \rho_{44} \end{vmatrix} \tag{13}$$

It is well known that P_4 for any covariance matrix can not be obtained in closed form. In the following discussion P_4 is computed by Plackett's method (1954) which reduces to closed form expression (Eq. 8) for the zero lag case.

We now make use of the result of Appendix 1, Eq. (12) and Van Vleck's (1966) formula $E[y_i y_j] = \frac{2}{\pi} \arcsin\rho_{ij}$ for i,j=1,2,3,4 and obtain the expression for fourth-product moment, i.e.

$$E[y_1 y_2 y_3 y_4] = 1 + \frac{4}{\pi^2}[2I_1+2I_2+I_3+I_4] \tag{14}$$

where I_1, I_2, I_3 and I_4 are given in the Appendix 1 (equations A1-15, 16, 17, 18).

Substituting Eq. (14) into Eq. (11), one obtains

$$\mathrm{Var}(\hat{r}_c(\tau)) = [\frac{1}{T}\int_{-T}^{T}(1-\frac{|n|}{T})E[y_1 y_2 y_3 y_4]dn] - E^2[\hat{r}_c(\tau)] \tag{15}$$

$$= 1 + [\frac{4}{\pi^2 T}\int_{-T}^{T}(1-\frac{|n|}{T})[2I_1+2I_2+I_3+I_4]dn] - E^2[\hat{r}_c(\tau)] \tag{16}$$

Since

$$\int_{-T}^{T} (1 - \frac{|n|}{T}) I_3 dn = \int_{-T}^{T} (1 - \frac{|n|}{T}) I_4 dn$$

Eq. (16) can be simplified to

$$\text{var}[\hat{r}_c(\tau)] = 1 + [\frac{4}{\pi^2 T} \int_{-T}^{T} (1 - \frac{|n|}{T})[2I_1 + 2I_3 + 2I_3] dn] - E^2[\hat{r}_c(\tau)] \quad (17)$$

Estimation of the Slope of the Quadrature Correlation Function ($R(\tau)$) at Zero Delay, When the Maximum Value of $R(\tau)$ is used as an Estimator.

In this section, the 'slope' of the quadrature correlation function at zero lag is estimated by the maximum value of the quadrature correlation function, i.e.

$$\text{Slope} = \hat{S}_m = \frac{\hat{R}_m(\tau_o) - \hat{R}(0)}{\tau_o} \quad (18)$$

Here $\hat{R}_m(\tau_o)$ is the estimated maximum value of $R(\tau)$ occurred at lag τ_o.

If $R(\tau)$ is estimated by the Analog method, (see Fig. 1), then the slope estimator is given by:

$$\hat{S}_{AN} = \frac{\hat{R}_{\alpha\beta}(\tau_o) - \hat{R}(0)}{\tau_o} \quad (19)$$

the expected value of this estimator is given by

$$E[\hat{S}_{AN}] = \frac{E[\hat{R}_{\alpha\beta}(\tau_o)]}{\tau_o} = \frac{R_{\alpha\beta}(\tau_o)}{\tau_o} \quad (20)$$

If $R(\tau)$ is estimated by the Polarity-coincidence method, then

$$\hat{S}_{PCC} = \frac{r_c(\tau_o) - r_c(0)}{\tau_o} \quad (21)$$

the expected value of this estimator is given by

$$E[\hat{S}_{PCC}] = \frac{E[\hat{r}_c(\tau_o)]}{\tau_o} = \frac{1}{\tau_o} r_c(\tau_o) = \frac{2}{\pi} \frac{1}{\tau_o} \arcsin R_{\alpha\beta}(\tau_o) \quad (22)$$

Variance Calculations:

The variance of the slope estimator is given by:

$$\tau_o^2 \text{var}[\hat{S}_m] = \text{var}[\hat{R}_m(\tau_o)] + \text{var}[\hat{R}(0)] - 2E[\hat{R}_m(\tau_o)\hat{R}(0)] \tag{23}$$

The variance of $\hat{R}_m(\tau_o)$ and $\hat{R}(0)$ can be computed by the methods discussed in the earlier section for both analog and polarity-coincidence cases. Now a method is derived to compute the third term for both cases. When $\hat{R}_m(\tau_o)$ and $\hat{R}(0)$ are computed by Analog method, then

$$\hat{R}(0) = \frac{1}{T}\int_0^T \alpha(t)\ \beta(t)dt$$

and

$$\hat{R}_m(\tau_o) = R_{\alpha\beta}(\tau_o) = \frac{1}{T}\int_0^T \alpha(t)\beta(t-\tau_o)dt \tag{24}$$

So $E[\hat{R}_m(\tau_o)\hat{R}(0)]$ is given by:

$$E[\hat{R}_m(\tau_o)\hat{R}(0)] = \frac{1}{T^2} E[\int_0^T \alpha(u)\beta(u)du \int_0^T \alpha(v)\beta(v-\tau_o)dv]$$

$$= \frac{1}{T^2}\int_0^T\int_0^T E(\alpha(u)\beta(u)\alpha(v)\beta(v-\tau_o))du\ dv \tag{25}$$

If α and β are jointly Gaussian, then

$$E[\alpha(u)\beta(u)\alpha(v)\beta(v-\tau_o)] = R_{\alpha\beta}(u-v+\tau_o)\ R_{\beta\alpha}(u-v) + R_{\alpha\alpha}(u-v)\ R_{\beta\beta}(u-v+\tau_o) \tag{26}$$

If $u-v = \eta$, then Eq. (25) can be rewritten as

$$E[\hat{R}_m(\tau_o)\hat{R}(0)] = \frac{1}{T}\int_{-T}^{T}\left(1-\frac{|\eta|}{T}\right)\left(R_{\alpha\alpha}(\eta)R_{\beta\beta}(\eta+\tau_o) - R_{\alpha\beta}(\eta)R_{\alpha\beta}(\eta+\tau_o)\right)d\eta \tag{27}$$

If $\hat{R}_m(\tau_o)$ and $\hat{R}(0)$ are computed by polarity coincidence method, then

$$\hat{R}(0) = \hat{r}_c(0) = \frac{1}{T}\int_0^T \text{Sgn}\ \alpha(t)\ \text{Sgn}\ \beta(t)\,dt \tag{28}$$

and $$\hat{R}_m(\tau_o) = r_c(\tau_o) = \frac{1}{T}\int_0^T \text{Sgn}\,\alpha(t)\ \text{Sgn}\,\beta(t-\tau_o)\,dt \qquad (28)$$

So $E[r_c(\tau_o)\hat{r}_c(0)]$ is given by:

$$E[\hat{r}_c(\tau_o)\hat{r}_c(0)] = \frac{1}{T^2}\int_0^T\int_0^T E[\text{Sgn}\,\alpha(u)\ \text{Sgn}\,\beta(u)\ \ \text{Sgn}\,\alpha(v)\ \ \text{Sgn}\beta(v-\tau_o)]\,du\,dv \qquad (29)$$

If $yy_1 = \text{Sgn}\,\alpha(u)$

$yy_2 = \text{Sgn}\,\beta(u)$

$yy_3 = \text{Sgn}\,\alpha(v)$

$yy_4 = \text{Sgn}\,\beta(v-\tau_o)$

then, using Eq. (12) and Eq. (A3-12), one can obtain the expression for the fourth-product momment $E[yy_1\ yy_2\ yy_3\ yy_4]$ (similar to Eq. (14)),

$$E[yy_1\ yy_2\ yy_3\ yy_4] = 1 + \frac{4}{\pi^2}[VI_1 + VI_2 + VI_3 + VI_4] \qquad (30)$$

where VI_1, VI_2, VI_3, and VI_4 are given in Appendix 3 (Equations A3-8,9,10,11).

Substituting Eq. (30) in Eq. (29), one obtains

$$E[\hat{r}_c(\tau_o)\hat{r}_c(0)] = \frac{1}{T}\int_{-T}^{T}\left(1 - \frac{|n|}{T}\right)E[yy_1\ yy_2\ yy_3\ yy_4]\,dn$$

$$= 1 + \left(\frac{4}{\pi^2}\right)\frac{1}{T}\int_{-T}^{T}\left(1 - \frac{|n|}{T}\right)(VI_1 + VI_2 + VI_3 + VI_4)\,dn \qquad (31)$$

Substitution of Eqs. (27) and (31) in Eq. (23), one obtains the variance of the slope estimator $[\hat{S}_m]$ for both anlaog and polarity-coincidence methods and using Eqs. (3,5,8,17,20,22,23) and Eqs. (9) and (10), one can compare the two estimators on the basis of signal to noise ratio.

Functional Form of Doppler Spectrum

In the report (12/11/77 - 1/11/78), the asymmetrical Doppler spectrum, at small antenna offsets from boresight, was represented by Gram-Charlier expansion. This expansion has been modified here in such a way that the first four central moments of the expansion are identical to that of the spectrum derived from the combined antenna pattern and angular dependence. The modified Gram-Charlier expansion of the spectrum S(f) is written as

$$S(f) = \frac{1}{\sqrt{2\pi m_2}}\left(\exp\left(-\frac{1}{2}\left(\frac{f-m_1}{\sqrt{m_2}}\right)^2\right)\right)\left[1 + \frac{\left(s_k - \frac{3m_1^3}{m_2^{1.5}}\right)}{3!} H_3\left(\frac{f-m_1}{\sqrt{m_2}}\right)\right.$$

$$\left. + \left(E_x + \frac{14m_1^4}{m_2^2} - \frac{12m_1^2}{m_2}\right) H_4\left(\frac{f-m_1}{\sqrt{m_2}}\right) + \frac{s_k^2}{2!3!3!} H_6\left(\frac{f-m_1}{\sqrt{m_2}}\right)\right] \qquad (32)$$

The autocorrelation function $R(\tau)$ of the spectrum S(f) defined as

$$R(\tau) = \frac{1}{2\pi}\int_{-\infty}^{\infty} S(\omega)\, e^{j\omega t} d\omega \qquad (33)$$

is obtained by manipulation as:

$$R(\tau) = \left(\exp\left(jm_1\tau - \frac{m_2\tau^2}{2}\right)\right)\left[1 - j\left(\frac{s_k m_2^{1.5}}{6} - \frac{3m_1^3}{6}\right)\tau^3 + \right.$$

$$\left. \left((E_x) + \frac{14m_1^4}{m_2^2} - \frac{12m_1^2}{m_2}\right)\frac{m_2^2\tau^4}{24} - \frac{s_k^2 m_2^3}{72}\tau^6\right] \qquad (34)$$

The first derivative of Eq. (34), which will be used in alignment accuracy analysis is given as:

$$\dot{R}(\tau) = (\exp(j m_1 \tau - \frac{m_2 \tau^2}{2}))\left[j m_1 - m_2 \tau - j(\frac{s_K m_2^{1.5}}{2} - \frac{3}{2} m_1^3)\tau^2 \right.$$
$$+ (\frac{m_1 s_K m_2^{1.5}}{6} + \frac{(E_x) m_2^2}{6} - \frac{m_1^4}{2})\tau^3$$
$$+ j(\frac{(E_x) m_2^2 m_1}{24} + \frac{s_K m_2^{2.5}}{6})\tau^4 - (\frac{(E_x) m_2^3}{24} + \frac{s_K^2 m_2^3}{12})\tau^5$$
$$\left. - j \frac{m_1 s_K^2 m_2^3}{72} \tau^6 + \frac{s_K^2 m_2^4}{72} \tau^7 \right] \qquad (35)$$

Accuracy Analysis of the Correlation Method of Alignment

In the report 12/11/77-1/11/78, it was shown that the spectral moments are functions of tropolink-parameters such as wind-speed, antenna beam width, angular dependence, transmitted frequency, the distance between the transmitter and the receiver, etc. The antenna elevation angle is assumed zero. The variation in the link parameters cause these coupled spectral moments to change accordingly. So simply varying these moments will mimic the different link conditions, the net effect of which will result in changed moments. In Table 1, with m_1=0, the effect of fade rate under different 'skew' (asymmetric) conditions is shown. Although with different 'skew' conditions, m_1 should correspondingly be non-zero, but in calculations, first m_1 is assumed zero (Table 1) and then for a given m_2, m_1 is varied (Table 2). For a given skew coefficient, the difference in m_1 can account for the 'residual clock-offset'. From Table 1, it could be observed that if the spectral width (or the fade rate) increases by a factor of 2, the variance decreases by the same factor. The theoretical explanation is given

in Appendix 2. The clipping loss, defined as in Eq. (10), is in the range of -1.5 to -3 db. In Table 3, the case of the symmetrical Doppler spectrum is considered. In Table 2 and 3, it should be noted that in some cases the clipping loss could result in the clipping gain. It would be of significant interest to identify those cases a priori. From Tables1, 2, and 3 it can be concluded that the variance decreases by the same factor as the averaging time is increased.

If the slope is estimated from the correlation function (Eq. 18), then it could be observed from the equations 23, 27 and 31, that the variance of the slope in both cases will decrease as the spectral width (or fade rate) is increased which is different than that of the slope estimation by True and hard-limiter method (report 11/12/77-1/11/78) where the variance increases in proportion to the fade rate. So it can be concluded that the slope estimation by Eq. (18) is 'better' than the estimation by True and hard-limiter methods.

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Appendix 1

In this Appendix the expression for P_4 (quadrivariate normal orthant probability) is derived. For 4 correlated normal variables, with zero mean and unit variance, the probability that all 4 variables will be positive is

$$P_4 = \int_0^\infty\int\int\int \phi\,(x,x_2,x_3,x_4)\; dx_1 dx_2 dx_3 dx_4 \qquad \text{(A1-1)}$$

Where $\phi(x_1,x_2,x_3,x_4)$ is the joint normal density of the Gaussian variables x_1, x_2, x_3, x_4 of zero mean and covariance matrix (c) given by equation (13). Since this matrix is symmetrical about the diagonal, only the upper-half is written as:

$$c = \begin{bmatrix} 1 & a & b & c \\ & 1 & d & b \\ & & 1 & a \\ & & & 1 \end{bmatrix} = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ & 1 & \rho_{23} & \rho_{24} \\ & & 1 & \rho_{34} \\ & & & 1 \end{bmatrix} \qquad \text{(A1-2)}$$

where
$$\begin{aligned} a &= r(\tau) \\ b &= \rho(\eta) \\ c &= r(\tau+\eta) \\ d &= r(\tau-\eta) \end{aligned} \qquad \text{(A1-3)}$$

The inverse of the covariance matrix (c) is given by:

$$c^{-1} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ & c_{22} & c_{23} & c_{24} \\ & & c_{33} & c_{34} \\ & & & c_{44} \end{bmatrix} \qquad \text{(A1-4)}$$

where

$$c_{11} = c_{44} = \frac{1-a^2-d^2-b^2+2abd}{|C^{-1}|}$$

$$c_{12} = c_{34} = -\frac{(a-a^3-bd+acd+ab^2-bc)}{|C^{-1}|}$$

$$c_{13} = c_{24} = \frac{ad-a^2b-b+ac+b^3-bcd}{|C^{-1}|}$$

$$c_{14} = -\frac{a^2d-2ab+c+b^2d-cd^2}{|C^{-1}|} \qquad \text{(A1-5)}$$

$$c_{22} = c_{33} = \frac{1-a^2-b^2-c^2+2abc}{|C^{-1}|}$$

$$c_{23} = -\frac{d-2ab+a^2c+b^2c-c^2d}{|C^{-1}|}$$

and $|C^{-1}| = 1-2a^2-d^2+4abd-2b^2+a^4-2a^2cd-2a^2b^2+4abc+b^4-2b^2cd-c^2+c^2d^2$.

The method followed to compute P_4 is the application of the general method given by Plackett [1954]. Let the correlation coefficients be denoted by ρ_{ij} (Eq. A1-2), then since the density function obeys the relation:

$$\frac{\partial \phi}{\partial \rho_{ij}} = \frac{\partial^2 \phi}{\partial x_i \partial x_j}$$

we have, for example

$$\frac{\partial P_4}{\partial \rho_{12}} = \int_0^\infty \int_0^\infty \left[\int_0^\infty \int_0^\infty \frac{\partial^2 \phi}{\partial x_1 \partial x_2} dx_1 dx_2 \right] dx_3 dx_4$$

$$= \frac{1}{2\pi(1-\rho_{12}^2)^{\frac{1}{2}}} P_2(c_{33}, c_{34}, c_{44}) \qquad \text{(A1-6)}$$

There will be 6 such equations, one for each correlation coefficient. Equation (A1-6) is a special case of Eq. (6) given by Plackett [1954].

Since

$$P_2[c_{33},c_{34},c_{44}] = \frac{1}{4} + \frac{1}{2\pi} \arcsin\left(\frac{-c_{34}}{(c_{33}c_{44})^{\frac{1}{2}}}\right) \tag{A1-7}$$

combining Eq. (A1-6) and (A1-7), we have

$$\frac{\partial P_4}{\partial \rho_{12}} = \frac{1}{8\pi(1-\rho_{12}^2)}\left[1 + \frac{2}{\pi}\arcsin\left[\frac{-c_{34}}{(c_{33}c_{44})^{\frac{1}{2}}}\right]\right] \tag{A1-8}$$

There are six such equations, upon combining them we obtain

$$P_4 = P_4[k_0] + \frac{1}{8\pi}\sum \int_{k_{ij}}^{\rho_{ij}}\left[1 + \frac{2}{\pi}\arcsin\left(\frac{-c_{pq}}{(c_{pp}c_{qq})^{\frac{1}{2}}}\right)\right]\frac{d\lambda_{ij}}{\sqrt{1-\lambda_{ij}^2}} \tag{A1-9}$$

where (p,q,i,j) is a permutation of $(1,2,3,4)$.

If $P_4[k_0]$ is the normal orthant probability of four Gaussian variables of zero mean, unit variance and covariance matrix

$$\begin{bmatrix} 1 & 0 & 1 & 0 \\ & 1 & 0 & 1 \\ & & 1 & 0 \\ & & & 1 \end{bmatrix} \tag{A1-10}$$

then

$$P_4 = P_4[k_0] + \frac{1}{8\pi}\left[2\int_0^a\left[1+\frac{2}{\pi}\arcsin\frac{(-c_{34})}{(c_{33}c_{44})^{\frac{1}{2}}}\right]\frac{d\lambda_{12}}{\sqrt{1-\lambda_{12}^2}}\right.$$

$$+ 2\int_1^b\left[1+\frac{2}{\pi}\arcsin\frac{(-c_{24})}{(c_{22}c_{44})^{\frac{1}{2}}}\right]\frac{d\lambda_{13}}{\sqrt{1-\lambda_{13}^2}}$$

$$+ \int_0^c\left[1+\frac{2}{\pi}\arcsin\frac{(-c_{23})}{(c_{22}c_{33})^{\frac{1}{2}}}\right.\frac{d\lambda_{14}}{\sqrt{1-\lambda_{14}^2}}$$

$$\left.+ \int_0^d\left[1+\frac{2}{\pi}\arcsin\frac{(-c_{14})}{(c_{11}c_{44})^{\frac{1}{2}}}\right.\frac{d\lambda_{23}}{\sqrt{1-\lambda_{23}^2}}\right] \qquad \text{(A1-11)}$$

$P_4[k_0]$ can be computed from Cheng [1968] e.g.

$$P_4[k_0] = \phi(0,1) \text{ of Cheng} = \frac{1}{4} \qquad \text{(A1-12)}$$

Combining (A1-11) and (A1-12), one can obtain

$$P_4 = \frac{1}{8} + \frac{1}{8\pi}\left[2\sin^{-1}a + 2\sin^{-1}b + \sin^{-1}c + \sin^{-1}d\right] + \frac{1}{4\pi^2}\,FPM \qquad \text{(A1-13)}$$

where

$$FPM=\left[2\int_0^a \arcsin\left[\frac{-c_{34}}{(c_{33}c_{44})^{\frac{1}{2}}}\right]\frac{d\lambda_{12}}{\sqrt{1-\lambda_{12}^2}}\right]+\left[2\int_1^b \arcsin\left[\frac{-c_{24}}{(c_{22}c_{44})^{\frac{1}{2}}}\right]\frac{d\lambda_{13}}{\sqrt{1-\lambda_{13}^2}}\right]$$

$$+\left[\int_0^c \arcsin\left[\frac{-c_{23}}{(c_{22}c_{33})^{\frac{1}{2}}}\right]\frac{d\lambda_{14}}{\sqrt{1-\lambda_{14}^2}}\right]+\left[\int_0^d \arcsin\frac{-c_{14}}{(c_{11}c_{44})^{\frac{1}{2}}}\frac{d\lambda_{23}}{\sqrt{1-\lambda_{23}^2}}\right] \qquad \text{(A1-14)}$$

Substitution of c_y from (A1-5) into (A1-14), one obtains:

$$FPM = 2I_1 + 2I_2 + I_3 + I_4$$

where

$$I_1 = \int_0^a \frac{dA}{\sqrt{1-A^2}} \arcsin\left[\frac{(A-A^3-BD+ACD+AB^2-BC)}{(1-A^2-B^2-D^2+2ABD)^{\frac{1}{2}}(1-A^2-B^2-C^2+2ABC)^{\frac{1}{2}}}\right]$$

$$I_2 = \int_1^b \frac{dB}{\sqrt{1-B^2}} \arcsin\left[\frac{(B+A^2B-AD-AC-B^3+BCD)}{(1-A^2-B^2-D^2+2ABD)^{\frac{1}{2}}(1-A^2-B^2-C^2+2ABC)^{\frac{1}{2}}}\right]$$

$$I_3 = \int_0^c \frac{dC}{\sqrt{1-C^2}} \arcsin\left[\frac{(D-2AB+A^2C+B^2C-C^2D)}{(1-A^2-B^2-C^2+2ABC)}\right]$$

and

$$I_4 = \int_0^d \frac{dD}{\sqrt{1-D^2}} \arcsin\left[\frac{(A^2D-2AB+C+B^2D-CD^2)}{(1-A^2-B^2-D^2+2ABD)}\right]$$

Since A, B, C, D are interrelated variables as in Eq. (A1-3), so variation in one results in the variation of another. So the above integrals I_1, I_2, I_3, I_4 can be changed as:

$$I_1 = \int_0^\tau \frac{\dot{r}(t')dt'}{\sqrt{1-r^2(t')}} \arcsin\left[\frac{(r(t')-r^3(t')-br(t'-n)+r(t')r(t'+n)r(t'-n)+r(t')+b^2-br(t'+n))}{(1-r^2(t')-b^2-r^2(t'-n)+2r(t')(b)r(t'-n))^{\frac{1}{2}} \times (1-r^2(t')-b^2-r^2(t'+n)+2r(t')(b)r(t'+n))^{\frac{1}{2}}}\right] \quad \text{(A1-15)}$$

$$I_2 = \int_0^n \frac{\dot{\rho}(n')dn'}{\sqrt{1-\rho^2(n')}} \arcsin\left[\frac{(\rho(n')+a^2\rho(n')-a(r(\tau-n')+r(\tau+n'))-\rho^3(n')+\rho(n')r(\tau+n')r(\tau-n')}{(1-a^2-\rho^2(n')-r^2(\tau-n')+2a\rho(n')r(\tau-n'))^{\frac{1}{2}}(1-a^2-\rho^2(n')-r^2(\tau+n')+2a\rho(n')r(\tau+n'))^{\frac{1}{2}}}\right] \quad \text{(A1-16)}$$

The integrals I_3 and I_4 are computed using the chain rule:

$$dC = \frac{dr(\tau'+n)}{d\tau'}\,d\tau'\Big|_{n=\text{constant}} + \frac{dr(\tau+n')}{dn'}\,dn'\Big|_{\tau=\text{constant}}$$

$$\text{and}\quad dD = \frac{dr(\tau'-n)}{d\tau'}\,d\tau'\Big|_{n=\text{constant}} - \frac{dr(\tau-n')}{dn'}\,dn'\Big|_{\tau=\text{constant}}$$

So

$$I_3 = \int_0^{\tau+n} \frac{\dot{r}(t')\,dt'}{\sqrt{1-r^2(t')}} \arcsin\left[\frac{r(t'-2n)-2r(t'-n)b+r^2(t'-n)r(t') + b^2r(t')-r^2(t')r(t'-2n))}{(1-r^2(t'-n)-b^2-r^2(t')+2r(t'-n)br(t')}\right]$$

$$+ \int_0^{\tau+n} \frac{\dot{r}(n')dn'}{\sqrt{1-r^2(n')}} \arcsin\left[\frac{(r(2\tau-n')-2a\rho(n'-\tau)+a^2r(n')+r(n') \rho^2(n'-\tau)-r^2(n')r(2\tau-n'))}{(1-a^2-\rho^2(n'-\tau)-r^2(n')+2a\rho(n'-\tau)r(n'))}\right] \qquad \text{(A1-17)}$$

Similarly

$$I_4 = \int_0^{\tau-n} \frac{\dot{r}(t')dt'}{\sqrt{1-r^2(t')}} \arcsin\left[\frac{(r(t'+2n)-2br(t'+n)+r(t')(r^2(n+t')+b^2) - r^2(t')r(t'+2n))}{(1-r^2(t'+n)-b^2-r^2(t')+2br(t')r(t'+n))}\right]$$

$$+ \int_0^{\tau-n} \frac{\dot{r}(n')dn'}{\sqrt{1-r^2(n')}} \arcsin\left[\frac{(r(2\tau-n')-2a\rho(\tau-n')+(a^2+\rho^2(\tau-n'))r(n') -r^2(n')r(2\tau-n'))}{(1-a^2-\rho^2(\tau-n')-r^2(n')+2a\rho(\tau-n')r(n'))}\right] \qquad \text{(A1-18)}$$

Substituting equations (A1-15,16,17,18) in Eq. (A1-13), one obtains

$$P_4 = \frac{1}{16}\left[1+1+\frac{2}{\pi}\left[2\sin^{-1}a+2\sin^{-1}b+\sin^{-1}c+\sin^{-1}d\right] + \frac{4}{\pi^2}\left[2I_1+2I_2+I_3+I_4\right]\right] \qquad \text{(A1-19)}$$

Appendix 2

In this Appendix, the effect of the change in the width of the Doppler spectrum on the variance of the two estimators of the quadrature correlation function at all lags is considered. Since the variance is inversely proportional to the averaging time and the spectral width is an indicator of fade rate, so the effect of the different fade rates (due to different wind velocities, antenna patterns, etc.) on the required averaging time is estimated by assuming that the total received power is the same under various fading conditions, e.g. if the Doppler spectrum increases in width by a factor of k, then

$$R_{\alpha\beta}(\tau) \rightarrow R_{\alpha\beta}(k\tau)$$

and (A2-1)

$$R_{\alpha\alpha}(\tau) \rightarrow R_{\alpha\alpha}(k\tau)$$

where $R_{\alpha\beta}(\tau)$ is the quadrature cross-correlation function and $R_{\alpha\alpha}(\tau)$ is the quadrature auto-correlation function of quadrature processes $\alpha(t)$ and $\beta(t)$. In deriving Eq. (A2-1), the well known Fourier transform scaling relationship is utilized, e.g.

$$\frac{1}{a} F(\frac{w}{a}) \leftrightarrow f(a\tau)$$

Substituting Eq. (A2-1) into Eqs. (3) and (15), one obtains, for large T,

$$\mathrm{Var}[\hat{R}_{\alpha\beta}(\tau)] = \frac{1}{KT} \int_{-T}^{T} (R^2_{\alpha\alpha}(n)+R_{\alpha\beta}(n+\tau)R_{\beta\alpha}(n-\tau)dn \qquad \text{(A2-2)}$$

and

$$\mathrm{Var}[\hat{r}_c(\tau)] = \frac{1}{kT} \int_{-T}^{T} E[y_1y_2y_3y_4]dn \qquad \text{(A2-3)}$$

where $\hat{r}_c(\tau)$ is the clipped quadrature correlation function.

From Eqs. (A2-2 and A2-3), it is evident that the variance of both estimators decreases by the same factor as the width of the Doppler spectrum increases. In other words, an increase in the width of the Doppler spectrum requires the decrease in the averaging time by the same factor.

Appendix 3

In this Appendix, the expression for P_4 (quadrivariate normal orthant probability) is derived which is required in computing the variance of the slope estimator by polarity coincidence method. The method is described in detail in Appendix 1 and has been applied in computing the variance of the quadration correlation function estimator by polarity coincidence method.

In the case under discussion, the covariance matrix (c) is given by

$$c = \begin{bmatrix} 1 & 0 & a & b \\ & 1 & c & d \\ & & 1 & g \\ & & & 1 \end{bmatrix} \qquad \text{(A3-1)}$$

where
$$\begin{aligned} a &= \rho(n) \\ b &= r(n+\tau_o) \\ c &= -r(n) = r(-n) \\ d &= \rho(n+\tau_o) \\ g &= r(\tau_o) \end{aligned} \qquad \text{(A3-2)}$$

The inverse of the covariance matrix (c) is given by:

$$c^{-1} = \begin{bmatrix} c_{11} & 0 & c_{13} & c_{14} \\ & c_{22} & c_{23} & c_{24} \\ & & c_{33} & c_{34} \\ & & & c_{44} \end{bmatrix} \qquad \text{(A3-3)}$$

where

$$c_{11} = \frac{1-g^2-c^2+2cdg-d^2}{|c^{-1}|}$$

$$c_{13} = \frac{-a+bg+ad^2-bcd}{|c^{-1}|}$$

$$c_{14} = \frac{ag-b-acd+bc^2}{|c^{-1}|}$$

$$c_{22} = \frac{1-a^2-b^2-g^2+2abg}{|c^{-1}|} \qquad \text{(A3-4)}$$

$$c_{23} = -\frac{c-gd+abd-b^2c}{|c^{-1}|}$$

$$c_{24} = \frac{cg-d+a^2d-abc}{|c^{-1}|}$$

$$c_{33} = \frac{1-b^2-d^2}{|c^{-1}|}$$

$$c_{34} = -\frac{g-cd-ab}{|c^{-1}|}$$

$$c_{44} = \frac{1-a^2-c^2}{|c^{-1}|}$$

and

$$|c^{-1}| = 1-g^2-c^2+2cgd-d^2+(-a^2+2abg+a^2d^2-2abcd)-b^2+b^2c^2$$

Similar to Eq. (A1-13), one can write

$$P_4 = \frac{1}{8} + \frac{1}{8\pi}\left[\arcsin a+\arcsin b+\arcsin c+\arcsin d+\arcsin g\right] + \frac{1}{4\pi^2}\,\mathrm{FPM} \qquad \text{(A3-5)}$$

where

$$\mathrm{FPM} = \left[\int_1^a \arcsin\left[\frac{-c_{24}}{(c_{22}c_{44})^{\frac{1}{2}}}\right]\frac{d\lambda_{13}}{\sqrt{1-\lambda_{13}^2}}\right] + \left[\int_0^b \arcsin\left[\frac{-c_{23}}{(c_{22}c_{33})^{\frac{1}{2}}}\right]\frac{d\lambda_{14}}{\sqrt{1-\lambda_{14}^2}}\right] \qquad \text{(A3-6)}$$

$$+ \left[\int_0^c \arcsin\left[\frac{-c_{14}}{(c_{11}c_{44})^{\frac{1}{2}}}\right]\frac{d\lambda_{23}}{\sqrt{1-\lambda_{23}^2}}\right] + \left[\int_1^d \arcsin\left[\frac{-c_{13}}{(c_{11}c_{33})^{\frac{1}{2}}}\right]\frac{d\lambda_{24}}{\sqrt{1-\lambda_{24}^2}}\right.$$

Substituting c_{ij} from (A3-4) into (A3-6), one obtains

$$FPM = VI_1 + VI_2 + VI_3 + VI_4 \tag{A3-7}$$

where

$$VI_1 = \int_1^a \frac{dA}{\sqrt{1-A^2}} \arcsin \left| \frac{(D+ABC-CG-A^2D)}{(1-A^2-B^2-G^2+2ABG)^{\frac{1}{2}}(1-A^2-C^2)^{\frac{1}{2}}} \right|$$

$$VI_2 = \int_0^b \frac{dB}{\sqrt{1-B^2}} \arcsin \left| \frac{(C-GD+ABD-B^2C)}{(1-A^2-B^2-G^2+2ABG)^{\frac{1}{2}}(1-B^2-D^2)^{\frac{1}{2}}} \right|$$

$$VI_3 = \int_0^c \frac{dC}{\sqrt{1-C^2}} \arcsin \left| \frac{(B+ACD-AG-BC^2)}{(1-G^2-C^2-D^2+2CDG)^{\frac{1}{2}}(1-A^2-C^2)^{\frac{1}{2}}} \right|$$

$$VI_4 = \int_1^d \frac{dD}{\sqrt{1-D^2}} \arcsin \left| \frac{(A+BCD-BG-AD^2)}{(1-G^2-C^2-D^2+2CDG)^{\frac{1}{2}}(1-B^2-D^2)^{\frac{1}{2}}} \right|$$

Since A,B,C,D are interrelated variables as in Eq. (A3-2), the variation in one results in the variation of another. So the above integrals I_1, I_2, I_3, and I_4 can be changed as

$$VI_1 = \int_1^n \frac{\dot{\rho}(n')dn'}{\sqrt{1-\rho^2(n')}} \arcsin \left[\frac{(\rho(n'+\tau_0)-\rho(n')r(n'+\tau_0)r(n')+gr(n')-\rho^2(n')\rho(n'+\tau_0)}{((1-\rho^2(n')-r^2(n'+\tau_0)-g^2+2g\rho(n')r(n'+\tau_0))^{\frac{1}{2}} \quad (1-\rho^2(n')-r^2(n'))^{\frac{1}{2}})} \right] \tag{A3-8}$$

$$VI_2 = \int_0^{\tau_0+n} \frac{\dot{r}(t')dt'}{\sqrt{1-r^2(t')}} \arcsin \left[\frac{(c-r(t'-n)\rho(t')+ar(t')\rho(t')-r^2(t')c)}{((1-a^2-r^2(t')-r^2(t'-n)+2ar(t')r(t'-n))^{\frac{1}{2}} \quad (1-r^2(t')-\rho^2(t'))^{\frac{1}{2}})} \right]$$

$$+ \int_0^{\tau_0+n} \frac{\dot{r}(n')dn'}{\sqrt{1-r^2(n')}} \arcsin \left[\frac{(-r(n'-\tau_0)-g\rho(n')+\rho(n'-\tau_0)r(n')\rho(n')+r^2(n')r(n'-\tau_0)}{((1-\rho^2(n'-\tau_0)-r^2(n')-g^2+2\rho(n'-\tau_0)r(n')g)^{\frac{1}{2}} \quad (1-r^2(n')-\rho^2(n'))^{\frac{1}{2}})} \right] \tag{A3-9}$$

$$VI_3 = -\int_0^{+n} \frac{\dot{r}(n')dn'}{\sqrt{1-r^2(n')}} \arcsin \left| \frac{(r(n'+\tau_0)-\rho(n')r(n')\rho(n'+\tau_0)-\rho(n')g-r^2(n')r(n'+\tau_0))}{((1-g^2-r^2(n')-\rho^2(n'+\tau_0)-2gr(n')\rho(n'+\tau_0))^{\frac{1}{2}} (1-\rho^2(n')-r^2(n'))^{\frac{1}{2}})} \right| \quad \text{(A3-10)}$$

$$VI_4 = \int_0^{\tau_0+n} \frac{\dot{\rho}(t')dt'}{\sqrt{1-\rho^2(t')}} \arcsin \left| \frac{(a+r(t')c\rho(t')-r(t')r(t'-n)-a\rho^2(t'))}{((1-c^2-\rho^2(t')-r^2(t'-n)+2c\rho(t')r(t'-n))^{\frac{1}{2}} (1-r^2(t')-\rho^2(t'))^{\frac{1}{2}})} \right|$$

$$+ \int_0^{\tau_0+n} \frac{\dot{\rho}(n')dn'}{\sqrt{1-\rho^2(n')}} \arcsin \left| \frac{(\rho(n'-\tau_0)-r(n')r(n'-\tau_0)\rho(n')-r(n')g-\rho(n'-\tau_0)\rho^2(n'))}{((1-g^2-r^2(n'-\tau_0)-\rho^2(n')-2gr(n'-\tau_0)\rho(n'))^{\frac{1}{2}} (1-r^2(n')-\rho^2(n'))^{\frac{1}{2}})} \right| \quad \text{(A3-11)}$$

Substituting equations (A3-8,9,10,11) in Eq. (A3-5), one obtains

$$P_4 = \frac{1}{16}[1+1+\frac{2}{\pi}[\arcsin a + \sin \arcsin b + \arcsin c + \arcsin d + \arcsin g]$$

$$+ \frac{4}{\pi^2}[I_1+I_2+I_3+I_4]] \quad \text{(A3-12)}$$

Part III

A New Complex Gaussian Troposcatter Channel Simulator

At the present there is an increasing interest in the use of communication channel simulators for the checkout and comparative testing of modems. The cost and difficulty of obtaining operating links and the impossibility of comparative modem testing with the same link (at the same time) have been the factors stimulating this interest. Another, less obvious factor, is the need for a simulator as a "standard channel" to be used in the calibration of channel measurement equipment. The only meaningful checkout of channel measurement equipment (and also modems) prior to on-the-air use involves a synthetic channel which can be set up to simulate known channel parameters.

The mathematical model around which the simulators, in the past, have been built is that of a band-limited uniform tapped delay line [Baghdady, 1969; Bello, 1969; Daly, 1964; Fitting, 1967; Klein, 1967; Hancock, 1966; Freudberg, 1965; Rose, 1966; Stein, 1965; Walker, 1966] with each tap undergoing independent fading according to complex Gaussian statistics. The choice of complex Gaussian statistics can be justified on the grounds of central limit theorem as applied to the contribution at each path delay caused by scattering from a large number of atmospheric refractive index inhomogenieties. Actually, it has been noted [Bennet, 1948] that as few as six sine waves with independently fluctuating random phase will give a fluctuating result whose envelope closely follows Rayleigh statistics and whose phase is uniformly distributed. Statistically, the problem of determining the resultant of a set of random phasors is familiar as that of two-dimensional random walk. A more basic view of the two-dimensional random walk follows

by regarding the constituent independently varying phasors to be resolved into quadrature components. The simultaneous values of the quadrature components of the resultant at any instant are then readily shown to be uncorrelated, and, by the central limit theorem, to independently approach Gaussian variates as the number of steps in the random walk (the number of contributing phasors) becomes large.

With regard to experiments, the short-term fading statistics of a received signal have often been observed to have a nearly Rayleigh distribution which is consistent with the complex Gaussian assumptions. It is well known that the received signal is the linear combination of the signals from the different paths (delays). The distinguishability of several paths implies that they are resolvable, i.e., their electric lengths are sufficiently different. More concretely, the situation usually described as 'multipath' is one in which more than one propagation path exists, with the time differentials between the several paths larger than the period of the highest 'significant' frequency components in the modulation of the transmitted signal.

Shortcommings of the Past Simulators. The above mentioned simulators, though, give adequate performance in the laboratory, but they have several shortcommings from a meteorological and communication point of view.

1. Aligned antennas are assumed. Normally antennas are less than optimally aligned, so the Doppler spectrum from the single tap is not necessarily symmetrical and the quadrature components therefore become statistically dependent processes.
2. Zero clock-offset is assumed. Normally there is clock-offset between the transmitting and receiving clocks, e.g., the clock frequencies are not identical. Also there is some drift present

in the clock, though the clocks used are usually fairly stable (1 in 10^{10}Hz). Both the effects, clock-offset and drifts of the clocks, should be included in the effective channel simulator.

3. There is no provision to include the average horizontal drift of the scatterers--a factor which is vitally important to a realistic model.
4. There is no provision to include the angular dependence of the scatterer which assigns a signal strength to the scatter as a function of the scattering angle.
5. There is no provision to directly include meteorological conditions. These simulators are not responsive to a change from turbulent conditions (fast fading) characterized by a Rayleigh envelope to an anisotropic medium (slow-fading) usually characterized by a Rician distributed envelope except by "brute force" method, i.e., forcing one scatterer to be very strong.
6. Airplane free common volume is assumed. Normally, while link is in operation, there are airplanes flying in the common-volume. Reflections from airplanes can be viewed as the reflections from a "large scatter" resulting in the 'v' shape instantaneous frequency of the return complex signal.

In the following description, a channel model is proposed in which the above-mentioned effects are included. This discussion will deal with the simulation of single tap in the tapped delay line model (or single path) of the channel. This model, in general, can be used for other channels (UHF, VHF, ionospheric channel, underwater channel, etc.). This channel model is divided into three parts as shown in Fig. 1.

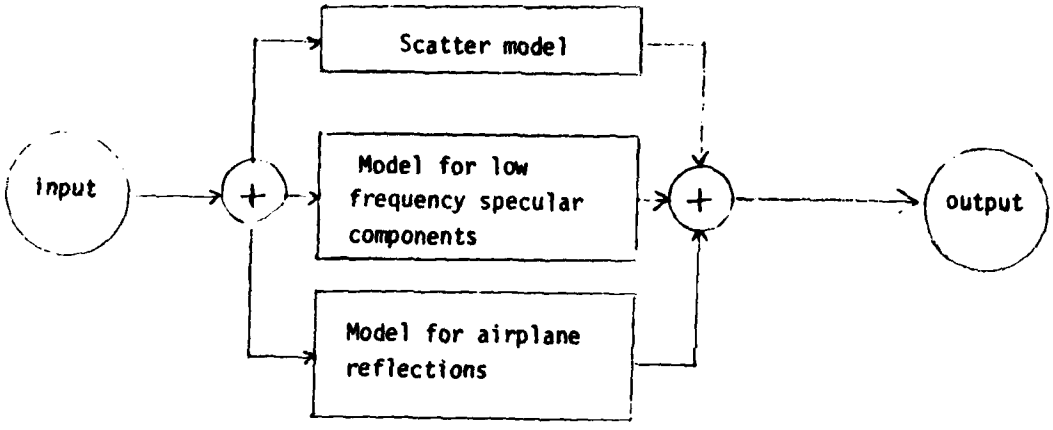


Fig. 1

Models for airplane reflections will be the topic of further research and will be discussed at a later date. In the following, a model for diffuse scattering such as would occur from a single turbulent atmospheric layer is discussed, and then a model for low frequency specular component is described.

Scatter Model. As mentioned earlier, the models in the past utilized the symmetrical Doppler spectrum with no clock-offset, the tap-gains were varied to represent the different fading conditions. In the proposed model, the other parameters of the tropo-channel are also included which mimic the effects of the clock-offset, misalignment of the antennas, spatial non-stationarities in the drifting scattering layers, etc. In the following discussion, only single tap-delay line (single path) model is considered for simplistic reasons.

In the report 12/11/77 - 1/11/78, it was shown that the received Doppler spectrum $S(f)$ could be represented as:

$$S(f) = COF[G_T(f)\ A(f)\ G_R(f)] \qquad (1)$$

where $G_T(f)$ and $G_R(f)$ are assumed Gaussian transmitter and receiver gain functions, $A(f)$ is the Angular Dependence function and COF is receiver 'clock-offset shift' operator. If there is no offset then received spectrum $S_o(f)$ can be represented as:

$$S_o(f) = G_T(f)\, A(f)\, G_R(f) \qquad (2)$$

$S(f)$ and $S_o(f)$ are related by: $S_o(f) = S(f+\Delta f)$ where Δf is the clock-offset.

If the transmitter and reciever antenna beam-widths are identical with Gaussian beam width "measure" of σ_o^2 and the transmitter is assumed pointed at the horizon over the great circle but the receiver antenna is azimuthally pointed at an angle α_a, then one obtains:

$$G_T(f) = G_o \exp\left(-\frac{f^2}{\sigma_o^2}\right) \qquad (3)$$

and

$$G_R(f) = G_o \exp\left(-\frac{(f-fa)^2}{\sigma_o^2}\right) \qquad (4)$$

In equations (3) and (4), (Merril, 1968)

$$fa = -\frac{2}{\lambda} v\, \alpha_a \quad \text{and} \quad \sigma_o^2 \equiv \frac{(d\alpha_3)^2}{(4\ell n2)} \qquad (5)$$

Where v is the cross-path wind velocity, λ is the wave length of the transmitted CW signal, $2d$ is the length of the link axis, α_3 is -3db beam-width of a single antenna pattern and G_o is constant.

Similarly angular dependence function is written as: (Merril, 1968)

$$A(f) = A_o[f^2+k_o^2]^{-11/6} \qquad (6)$$

Where A_o is constant depending upon the cross-path wind-velocity and intrinsic

strength of the scatterers and k_o is given by:

$$K_o = \frac{z_o}{d} \cdot \frac{2v}{\lambda} \tag{7}$$

z_o is the height of the layer in consideration. For small antenna misalignment and narrow beams, $A(f)$ can be approximated by:

$$A(f) = A_o[f^2+K_o^2]^{-2} \tag{8}$$

Simulation of the Complex Channel: In this discussion, the tropo-channel will be simulated and then the clock-offset effect will be included in the overall simulation. It is well known that a process with spectral density $S_o(f)$ can be generated by passing white noise through the filter of transfer function $H(S)$ such that:

$$|H(j\omega)|^2 = S_o(f)=G_T(f)\ A(f)\ G_R(f) \tag{9}$$

Similarly, if

$$|H_T(j\omega)|^2 = G_T(f)$$

$$|H_A(j\omega)|^2 = A(f) \tag{10}$$

and $$|H_R(j\omega)|^2 = G_R(f)$$

then one can write

$$|H_T(j\omega)|^2 = |H_T(j\omega)|^2\ |H_A(j\omega)|^2\ \ |H_R(j\omega)|^2 \tag{11}$$

Using equations (3), (4), (6), (10) and (11), one obtains

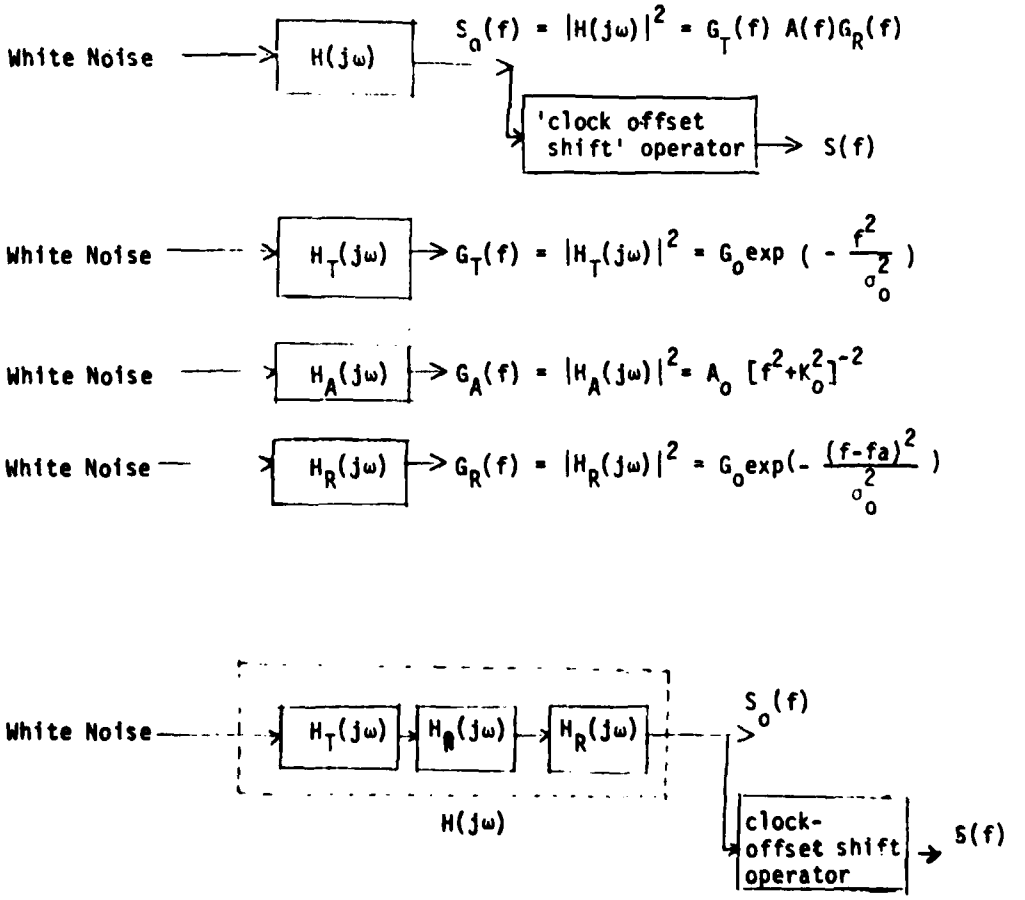
$$|H_T(j\omega)|^2 = G_o \exp\left[-\frac{f^2}{\sigma_o^2}\right] \tag{12}$$

$$|H_R(j\omega)|^2 = G_o \exp\left[-\frac{(f-fa)^2}{\sigma_o^2}\right] \qquad (13)$$

$$|H_A(j\omega)|^2 = A_o\,[f^2+K_o^2]^{-2} \qquad (14)$$

and $$|H(j\omega)|^2 = G_o^2\,A_o\,[f^2+K_o^2]^{-2}\ \exp\left[-\frac{f^2+(f-fa)^2}{\sigma_o^2}\right] \qquad (15)$$

eqs. (12) to (15) are shown in block-diagram form in Figure 2.



Block diagram forms of equations 12 - 15

Fig. 2

Some Properties of $|H(j\omega)|^2$. Here it is shown that the asymmetric filter H(S) causes the asymmetrical Doppler spectrum which results in the cross-correlation function of the output (of the filter) quadrature processes (inphase and quadrature). It has been mentioned in earlier reports that the misalignment of the antennas and the clock-offset both result in the output quadrature processes being correlated. It will be shown in the later section that by decomposing H(S) in even and odd components, one can directly relate the odd part of H(S) to the cross-correlation of the output processes.

The even and odd parts of $|H(j\omega)|^2$ are defined as:

$$\text{Ev}|H(j\omega)|^2 = \text{Even part of } |H(j\omega)|^2 = (1/2)|H(j\omega)|^2 + (1/2)|H(-j\omega)|^2$$

$$\text{and} \quad \text{OD}|H(j\omega)|^2 = \text{Odd part of } |H(j\omega)|^2 = (1/2)\,H(j\omega)|^2 - (1/2)|H(-j\omega)|^2 \tag{16}$$

From equation (16), it is clear that the odd part of $|H(j\omega)|^2$ will be zero if $|H(j\omega)|^2$ is symmetrical about the origin (i.e., zero clock-offset and aligned antennas). If the input process to the filter $H(j\omega)$ is symmetrical about the origin with spectral density $U(\omega)$ [constant if white noise] then the auto-spectrum, $S_{\alpha\alpha}(\omega)$ and cross-spectrum $S_{\alpha\beta}(\omega)$ of the output quadrature processes $\alpha(t)$ and $\beta(t)$, are given by [Frank, 1969]

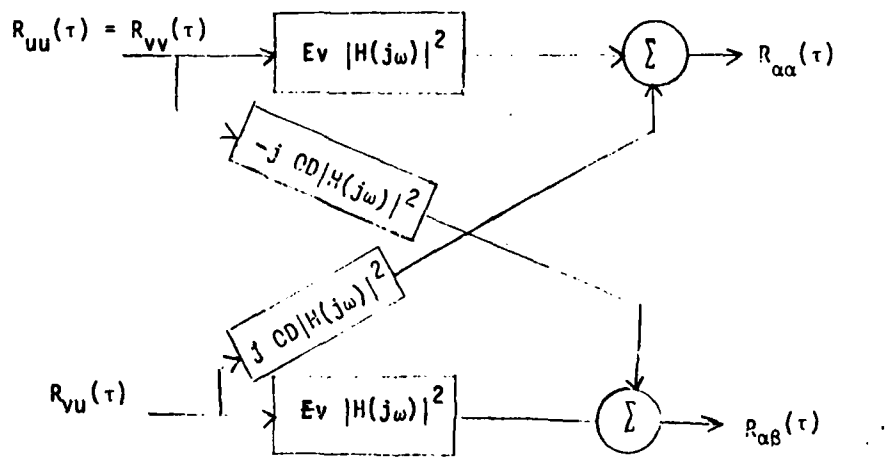
$$S_{\alpha\alpha}(\omega) = S_{\beta\beta}(\omega) = \text{Ev}\,|H(j\omega)|^2\; U(\omega)$$

$$\text{and} \quad S_{\alpha\beta}(\omega) = -j\,\text{OD}|H(j\omega)|^2\; U(\omega) \tag{17}$$

If input complex white noise is correlated and is of asymmetric spectrum (which results in auto spectral density $S_{uu}(\omega)$ and cross-spectral density $S_{uv}(\omega)$ of the input quadrature processes u(t) and v(t)), then [Frank, 1969]

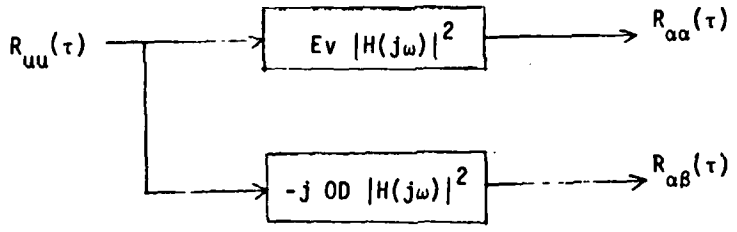
$$S_{\alpha\alpha}(\omega) = Ev\ H(j\omega)|^2\ S_{uu}(\omega) + j\ CD\ |H(j\omega)|^2 S_{vu}(\omega)$$
$$S_{\alpha\beta}(\omega) = -j\ OD\ |H(j\omega)|^2\ S_{uu}(\omega) + E_v|H(j\omega)|^2\ S_{vu}(\omega) \quad (18)$$

These linear transformations on auto-correlation and cross-correlation functions,not on the signals themselves,are shown symbolically in Fig. 3(a) and (b). Fig. 3(b) results from 3(a) when input process is white uncorrelated noise. These diagrams make it clear how non-symmetrical band-pass characteristics of the channal introduces correlation between inphase and quadrature components of the band pass process. Now a method is discussed to obtain H(S) from $|H(j\omega)|^2$ and the eigen-values of H(S) are then related to the tropo-link parameters. First, a general complex model will be derived, and this model is then applied to the tropo-channel.



Low-pass equivalent of transformation relating input and output into correlation functions when input Gaussian noise is correlated

Fig. 3(a)



Low pass equivalent of transformation when input Gaussian noise is uncorrelated

Fig. 3(b)

A Complex Model. The motivation to simulate the band-pass channel (filter) into the low-pass equivalents (or complex filter) stems from the fact that the inherent low-pass nature and speed limitations of the analog computer make its operation in the low-pass mode highly desirable. In the following discussion, we shall show how a band-pass system can be simulated equivalently by two inter-connected low-pass systems.

Consider the band-pass filter with transfer function R(f) and its low-pass equivalent H(f). The input signal is given by:

$$x_1(t) = \mathrm{Re}\left[z_1(t)\exp(j2\pi f_o t)\right]$$
$$=(1/2)z_1(t)\exp(j2\pi f_o t) + (1/2)z_1^*(t)\exp(-j2\pi f_o t) \qquad (19)$$

where $z_1(t) = u(t) - jv(t)$ (20)

Hence $X_1(f) = (1/2)Z_1(f-fo) + (1/2)Z_1^*(-f-fo)$ (21)

The transfer function of the filter can be expressed in terms of H(f) in a similar manner,

$$R(f) = (1/2)H(f-fo) + (1/2)H^*(-f-fo) \qquad (22)$$

where $H(f-fo) = (1+\mathrm{sgn}f)\,R(f)$ (23)

Now for the output signal,

$$X_2(f) = R(f)\, X_1(f)$$

$$=(1/4)H(f-fo)\, Z_1(f-fo) +(1/4)H^*(f-fo)\, Z_1{}^*(-f-fo)$$

$$=(1/2)Z_2(f-fo) +(1/2)Z_2{}^*(-f-fo) \qquad (24)$$

From eq. (24), it is evident that

$$Z_2(f) =(1/2)H(f)\, Z_1(f)$$

or $$z_2(t) =(1/2)h(t) \textcircled{X} z_1(t) \qquad (25)$$

Output $z_2(t)$ in complex form is written as

$$z_2(t) = \alpha(t)-j\beta(t) \qquad (26)$$

Now we decompose $h(t)$ into its real and imaginary parts so that

$$(1/2)h(t) = h_1(t) + j\, h_2(t), \qquad (27)$$

where $h_1(t)$ and $h_2(t)$ are real and can be considered as inpulse responses of real low-pass filters. The corresponding transfer functions are given by

$$H_1(f) = 1/4 \left[H(f) + H^*(-f)\right]$$

and $$H_2(f) =(1/4j)\left[H(f) - H^*(-f)\right] \qquad (28)$$

i.e., by the symmetrical and anti-symmetrical parts, respectively. It follows that $H_1(f)$ and $H_2(f)$ are related directly to the parts of the band-pass function $R(f)$ which are symmetrical and anti-symmetrical, respectively about the center frequency fo. $H_1(f)$ and $H_2(f)$ are related to even and odd parts of $|H(j\omega)|^2$ (eq. 16) by:

$$Ev|H(j\omega)|^2 = |H_1(f)|^2 + |H_2(f)|^2$$

and $$OD|H(j\omega)|^2 = jH_2(f)\,H_1^*(f) - jH_2^*(f)\,H_1(f) \qquad (29)$$

From examples (20), (25), (26) and (27), one writes:

$$z_2(t) = \alpha(t)\ j\beta(t) = (u\text{-}jv) \otimes (h_1 + j\,h_2)$$

$$= (u \otimes h_1 + v \otimes h_2) - j\,[v \otimes h_1 - u \otimes h_2] \qquad (30)$$

or in frequency domain

$$\alpha(f) = U(f)\,H_1(f) + V(f)\,H_2(f)$$

$$\beta(f) = V(f)\,H_1(f) - U(f)\,H_2(f) \qquad (31)$$

So by this approach, a single input, single output band pass filtering operation is replaced by a double input, double output low-pass filtering operation which characterizes separately the transfer of inphase and quadrature components. The equivalent low-pass system is represented schematically by the lattice arrangement shown in Fig. 4.

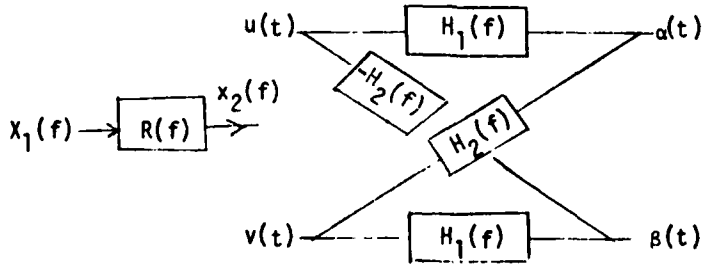


Fig. 4. Equivalent low-pass filtering.

A cascade combination of band-pass filters can be handled directly in terms of low-pass equivalents as shown in Fig. (5). [Frank, 1969]

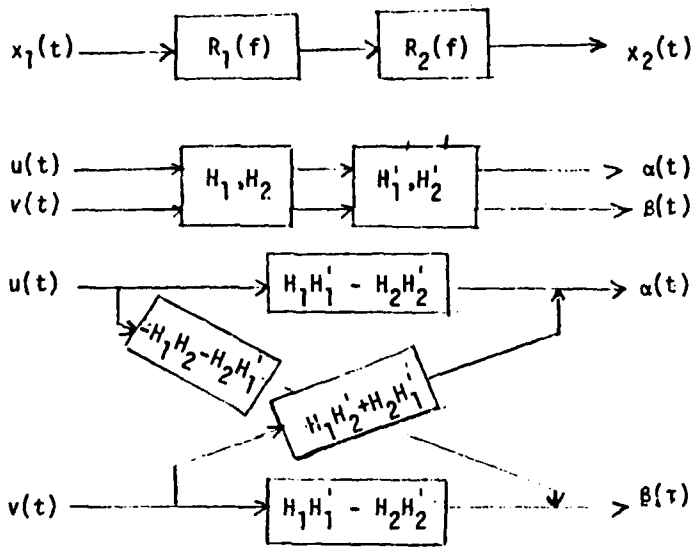


Fig. 5 Low-pass equivalents of cascade combination of band-pass filters

We should note that if a band-pass filter exhibits symmetry about f_0, then $H_2(f) = 0$ and there is no cross-coupling between the in-phase and quadrature components. This is the kind of transmission required to avoid amplitude to phase modulation conversion on a band pass signal.

In Appendix 1, a first order and second order complex system is derived which when driven by the complex white noise outputs the complex narrow-band process, In the following discussion, the eigen-values of the complex system are estimated from the first three spectral moments of the output Doppler spectrum (or complex spectrum). First, the individual blocks $[H_T(j\omega), H_R(j\omega), A(j\omega)]$ will be simulated, then the combined system $[H(j\omega)]$, simulating the tropo-link,will be synthesized.

Simulation of the Transmitter Gain Function (equation 12). Simulation of the transmitter gain function is the approximation of the Gaussian-magnitude approximation given by equation 12. Given the ideal Gaussian magnitude characteristic:

$$|H_T(j\omega)| = \exp(-\omega^2/2)$$

where the unit bandwidth has been selected as a matter of convenience, let us find an all-pole transfer function

$$H(s) = \frac{1}{G_n(s,\bar{a})}$$

where $G_n(s,\bar{a})$ *is a real Hurwitz polynominal with a coefficient vector* $\bar{a}$, whose spectrum approximates $|H_T(j\omega)|^2$ *best in the Taylor sense at the origin*, defining the error function as:

$$E(s,\bar{a}) = G_n(s,\bar{a})\ G_n(-s,\bar{a}) - \exp[-s^2]$$

We readily see that the optimum $G_n(s,\bar{a})\ G_n(-s,\bar{a})$ corresponds to the truncated Maclaurin expansion:

$$G_n(s,\bar{a})\ G_n(-s,\bar{a}) = 1 - s^2 + \frac{s^4}{2!} - \frac{s^6}{3!} + - - + (-1)^n\ \frac{s^{2^n}}{n!}$$

Finally, $G_n(s,\bar{a})$ is isolated from the product $G_n(s,\bar{a})\ G_n(-s,\bar{a})$ by factoring and retaining only LHP factors. Based upon the above analysis and renormalizing w.r.t. unit 3-db bandwidth, Dishal [1959] and Humphry [1970] obtained the pole locations up to the order $n = 10$. Increasing n, obviously, would give better 'matching' characteristics. But only the case for $n = 2$ would give symmetrical spectrum. So a *simple second-order complex model is considered and it is suggested that further work is necessary to obtain better 'matching' characteristics without distorting the symmetry.* By considering the pole locations at $a + jb$, where $a = -1.2841100\sigma_o$ and $b = \pm j.531895\sigma_o$ (σ_o is 3-db bandwidth given by equation 5), one obtains the second-order complex

model (see Appendix 1, equation A1-7) as in Fig. 6

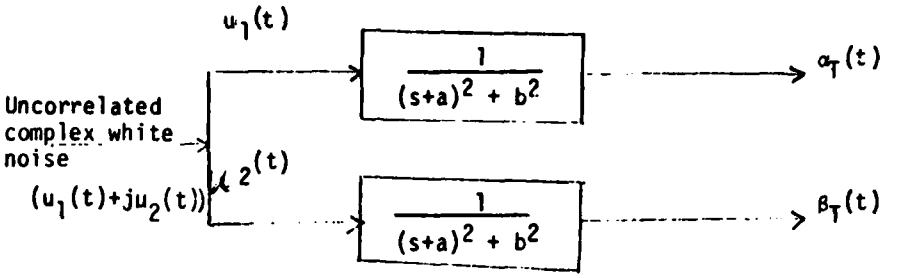


Fig. 6

Simulation of Angular Dependence (equation 14). The angular dependence function is given by equation 14, e.g.,

$$|H_A(j\omega)|^2 = \frac{A_o}{(f^2 + K_o^2)^2}$$

where K_o is given by equation (7). From the above equation, one obtains

$$H_A(s) = \frac{2\pi^{3/2}\sqrt{A_o/k_o}}{(s + 2\pi K_o)^2} \qquad (32)$$

The simulation of $H_A(s)$ in quadrature form can be obtained by assuming $a = c$, $b = d = 0$ in equation A1-3 of Appendix 1, and then substituting in equation A1-7, one obtains:

$$H_1(s) = H_A(s) \quad \text{and} \quad H_2(s) = 0$$

and

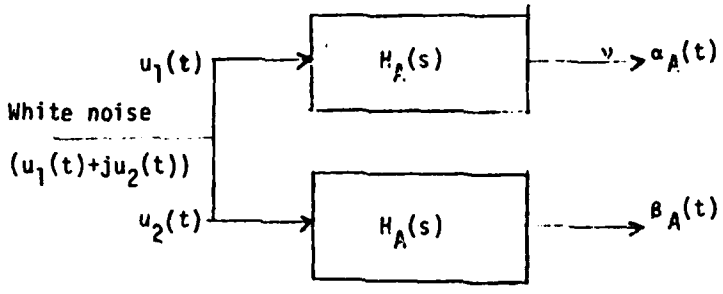


Fig. 7

Simulation of Receiver Antenna Gain Function (equation 13). Two methods are discussed to simulate the receiver antenna gain function given by equation (13). It is noted that the transmitter and receiver antennas are identical except that the receiver antenna is not pointed at the great-circle but is offset by an amount α_a corresponding to a Doppler offset of f_a.

Method 1. In this method, first the spectrum $|H_T(j\omega)|^2 |H_A(j\omega)|^2$ $(G_T(f)\ A(f))$ would be shifted left by an amount f_a. The shifted spectrum would, then, be multiplied by $|H_R(j\omega)|^2$ with $f_a = 0$ (it is equivalent to $|H_T(j\omega)|^2$). Finally, the spectrum would be shifted right by f_a. The overall simulation is shown in Fig. 8. The spectral-shift unit shown in Fig. 9 performs a single side-band modulation directly at baseband. The mathematics of the signal processing is outlined below. [Manske, 1968]

Consider the case in which a narrow-band signal, expressed in the form of $x(t) = I(t)\ \text{Cos}\omega_c t + Q(t)\ \text{sim}\omega_c t$ (33)

is passed through a filter having characteristics centered at a frequency

ω_1, which is different from ω_c by a small amount $(\omega_1 - \omega_c = f_a)$. The signal can then be expressed in terms of ω_1, rather than ω_c in the form of:

$$X(t) = \alpha_R(t)\cos\omega_1 t + \beta_R(t)\sin\omega_1 t \qquad (34)$$

From equations (33) and (34), one can obtain (see Fig. 9)

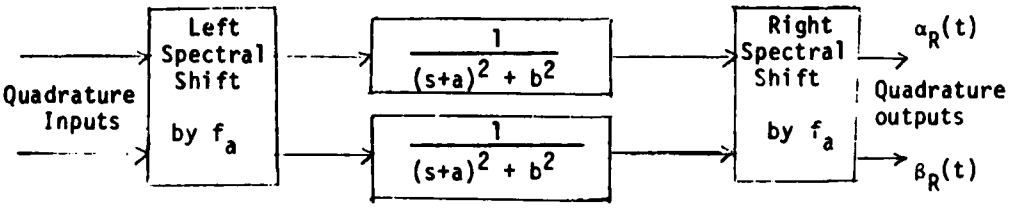


Fig. 8. Simulation of receiving antenna gain function (method 1)

$$\alpha(t) = I(t)\ \text{Cos}\ f_a t\ - Q(t)\ \text{Sin}\ f_a t$$

$$\text{and} \qquad \beta(t) = I(t)\ \text{Sin}\ f_a t\ + Q(t)\ \text{Cos}\ f_a t \qquad (35)$$

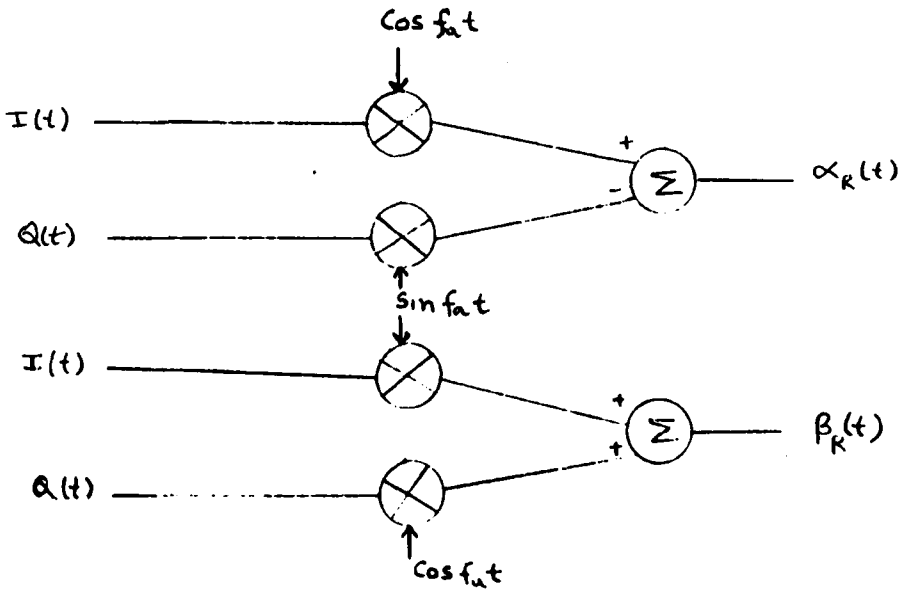


Fig. 9. Spectral-shift unit

Method 2. In this method, the receiver antenna gain function is simulated by the complex model as described in Appendix 1. If in equation (A1-3), one assumes $a = C = a_o$, $d = 0$, $b = bo$, then one can obtain from equation A1-7 that: [See Fig. 10]

$$H_1(s) = \frac{1}{(s+a_o)^2+b_o^2} \quad \text{and} \quad H_2(s) = \frac{b_o}{(s+a_o)[(s+a_o)^2+b_o^2]} \tag{36}$$

and from equation (A1-11 and 12), one obtains

$$\dot{R}(o) = -j\ \frac{b_o}{2} \quad \text{and} \quad \ddot{R}(o) = -\left(a_o^2+\frac{b_o^2}{2}\right) \tag{37}$$

Since the first moment (gives the average frequency of the spectrum) is equal to $\frac{1}{2\pi}\ \dot{R}(o)$ and the second central moment (related to $\ddot{R}(o)$) gives the 3-db band-width, one derives from equation 37, that

$$f_a = \left(-\frac{b_o}{2}\right)\frac{1}{2\pi} \quad \text{or} \quad b_o = -4\pi f_a \tag{38}$$

Similarly,

$$\sigma_o^2 = \frac{1}{(2\pi)^2}\left[a^2+\frac{b_o^2}{2} - \frac{b_o^2}{4}\right] = \frac{1}{(2\pi)^2}\left[a^2+\frac{b_o^2}{4}\right] \tag{39}$$

From equations (38) and (39), one obtains

$$a^2 = (2\pi)^2\left[\sigma_o^2 - f_a^2\right] \tag{40}$$

For $a^2 > o$, one requires that $|\sigma_o| > |fa|$ which is intuitively obvious.

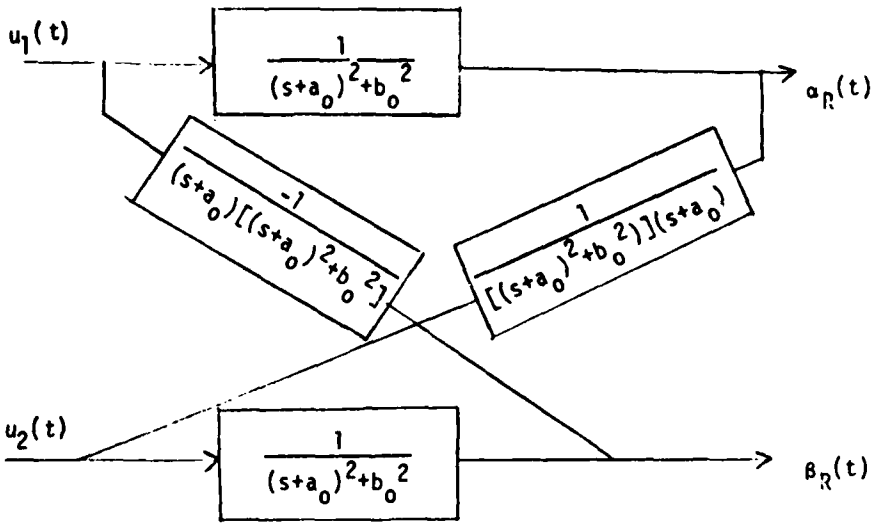


Fig. 10. Simulation of receiver antenna gain function (method 2)

Simulation of Clock-Offset [COF' operator, Equation 1]. It has been mentioned earlier that the clock-offset (Δf) merely shifts the spectrum either to the left or right depending upon the positive or negative clock-offset. The spectral-shift unit can be implemented similar to that shown in Fig. 9, by substituting Δf instead of f_a. Drift in the clock can be incorporated by varying Δf accordingly.

Over-all Tropo-Channel Transfer Function (Diffuse Scattering)

The overall channel transfer function in quadrature form is the cascaded simulation of various terms in equation 1 and is shown in Fig. 11.

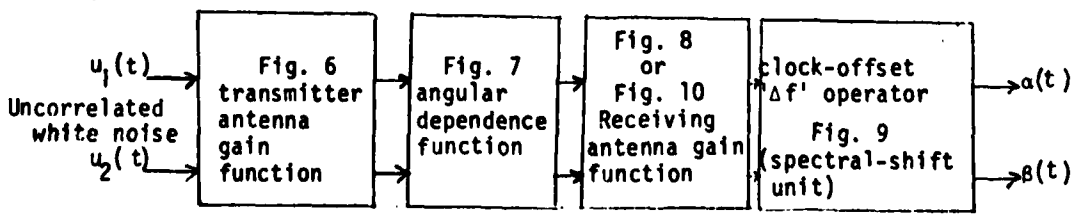


Fig. 11. Over-all tropo-channel simulator for diffused scattering

Using Fig. 5, one can obtain the cascade form of the transfer functions of transmitter and receiver antenna gain functions (Figs. 6 & 10) and angular dependence function (Fig. 7) as shown in Fig. 12, where

$$H_{cr} = \frac{1}{[(s+a)^2+b^2][s+k]^2[(s+a_o)^2+b_o^2]} \qquad (40)$$

and

$$H_{un} = \frac{1}{[(s+a)^2+b^2][s+k]^2(s+a_o)[(s+a_o)^2+b_o^2]} .$$

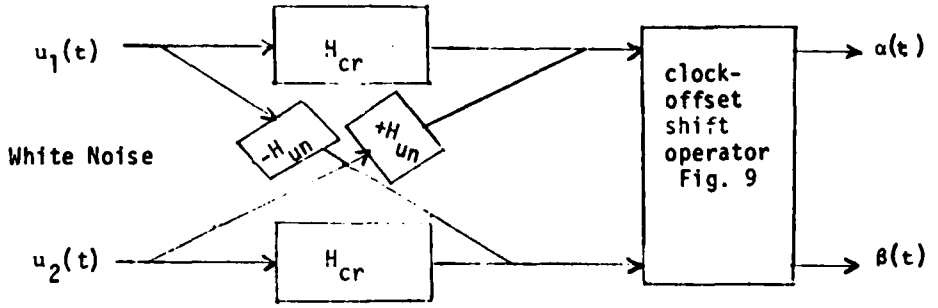


Fig. 12. Cascade form of over-all tropo channel simulator as shown in Fig. 11.

Models for Low Frequency Specular Components:

Duvoisin (1969) points out that in the presence of multiple scattering layers, the total Doppler power spectrum is the sum of the spectral contributions of the individual layers. The shape of the portion of the Doppler (power) · spectrum of the received signal caused by a given horizontal scattering layer can therefore be shown to be controlled by the large numbers of scattering points drifting across the scattering volume and is functionally represented by the equation 2. Considering equations (3 to 7), Duvoisin (1969) concluded

that the narrow power-peaks near zero Doppler could be produced by any one of the following conditions:

1. Very low values of cross-path wind, V.
2. Very narrow beam antennas pointed down the great circle azimuth.
3. Very narrow angular dependence function.

Since neither conditions(1) or (2) were satisfied during most of the Barrow, et al. (1968) rake sounding experiments, the specular peaks, in most cases, were probably caused by condition 3. The angular dependence function used in Birkemeier, et al.(1968) to simulate the narrow specular peaks observed in the rake data was of the form

$$A_n(f) = \left[\frac{2\pi A_n \ell_z}{V}\right]^{-p} \left[f^2 + \frac{k_o^2}{A_n^2}\right]^{-p/2} \tag{41}$$

where k_o is given by eq. 7, A_n is the degree of anisotropy, ℓ_z is the spatial correlation length in a vertical direction and p is $\frac{11}{3}$ for Tatarski scattering.

For $A_n = 1$ (isotropic case) and $p = \frac{11}{3}$, equation 41 reduces to the equation 6, where

$$A_o = \left[\frac{2\pi \ell_z}{V}\right]^{-11/3} \tag{42}$$

In eq. (41), the narrow-peaks can be obtained by either increasing p or increasing A_n. According to Duvoisin (1969), maintaining A = 1 and increasing p could produce sufficiently narrow specular peaks only when p was increased by almost two orders of magnitude. However, a power law of p = 11/3 and a degree of anisotropy of A = 20 produced peaks having the necessary Doppler bandwidth. So equation 41 can be rewritten as:

$$A_n(f) = A_o A_n^{-11/3} \left[f^2 + \frac{k_o^2}{A_n^2}\right]^{-11/6} \tag{43}$$

Similar to equation 8, for small antenna misalignment, A(f) can be approximated by:

$$A_n(f) = A_{on} \; [f^2 + k_{on}^2]^{-2} \tag{44}$$

where $A_{on} = A_o \, A_n^{-11/3}$ and $k_{on} = k_o / A_n$ (45)

Now similar to equation 32 and Fig. 7, one can obtain

$$H_{An}(s) = \frac{2\pi^{3/2} \sqrt{(A_{on}/k_{on})}}{(S+2\pi k_{on})^2} \tag{46}$$

and

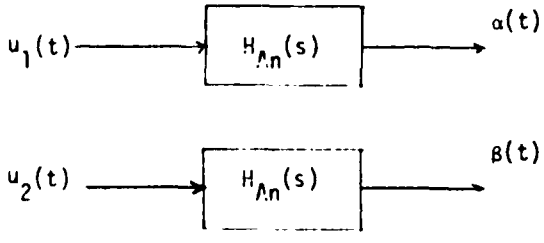


Fig. 13

Now similar to Fig. 11, one can obtain the overall tropo-channel simulator for low frequency specular components i.e.,

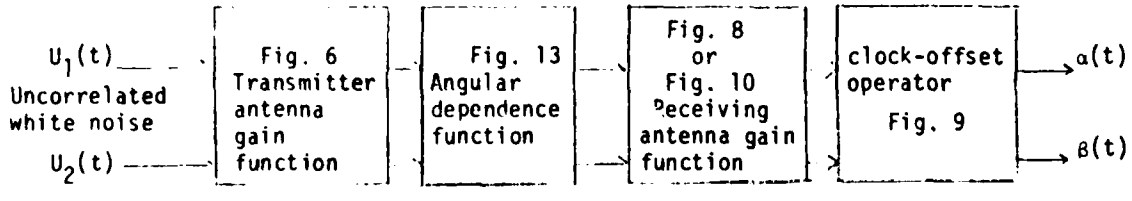


Fig. 14. Overall tropo-channel simulator for low-frequency specular components.

Overall tropo-channel transfer function can be obtained by combining Fig. (11) and (14) and is given in Fig. 15.

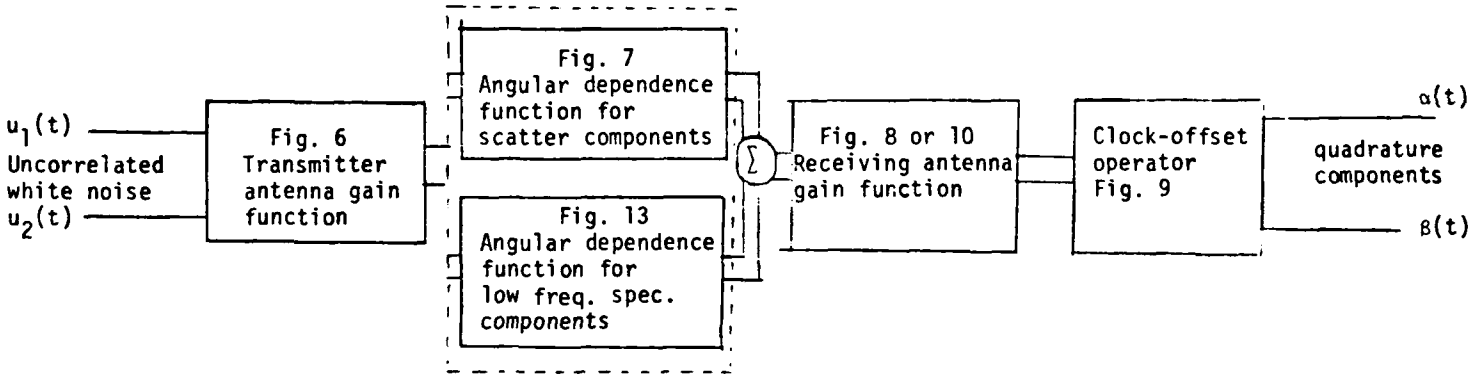


Fig. 15. Overall tropo-channel simulator for diffused and specular components

Model for the Average Drift of the Scatters:

In the simulation of the angular dependence function, symmetrical form of the function is assumed. Since we would expect on the average as many up-Doppler signals as down-Doppler signals and therefore, the average total doppler-shift for aligned antennas would be zero. If there are more scatters on one side of the great circle, it results in the average frequency (f_d) to be non-zero and the simulation of the angular dependence function (as shown in Fig. 7 and 13) would be modified. Using the results of the Appendix 1 (A1-15), one obtains:

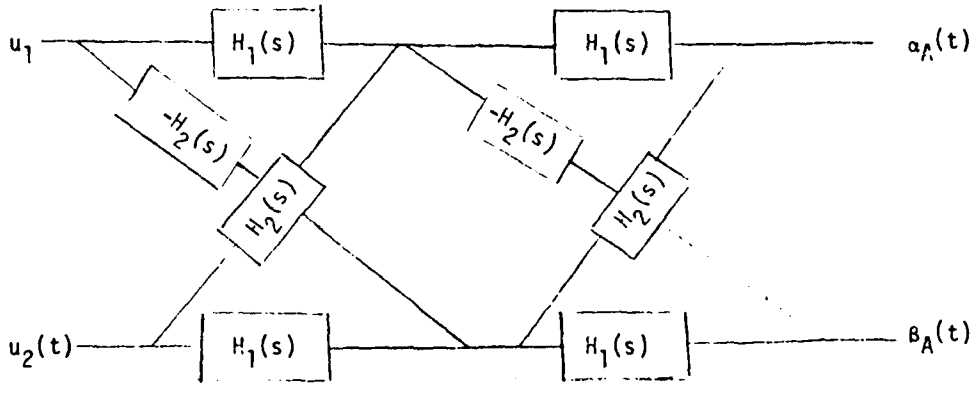


Fig. 16

where

$$H_1(s) = \left(2\pi^{3/2}\sqrt{A_{on}/k_{on}}\right) \frac{(s+2\pi k_{on})}{(s+2\pi k_{on})^2+\Delta A^2} \qquad (46)$$

$$H_2(s) = \left(2\pi^{3/2}\sqrt{A_{on}/k_{on}}\right) \frac{\Delta A}{(s+2\pi k_{on})^2+\Delta A^2}$$

Now similar to equation (38), one can obtain:

$$\Delta A = 2\pi f_d \qquad (47)$$

If the horizontal drift of the scattering is occuring in a deterministic or random fashion, then ΔA (the imaginary part of the complex pole $-\tilde{k} = 2\pi k_{on} + j\Delta A$) can be varied accordingly.

Examples:

In Fig. 12 a tropo-scatter channel simulator for diffused layer is shown. The poles of this channel transfer function are related to the tropo-link parameters. The variations in the pole locations would correspond to various link conditions, resulting in different spectral moments as described in earlier reports. In the following , for illustrative purposes, the pole locations $[-\tilde{k}_1,-\tilde{k}_2]$ of a 2nd-order complex system are varied to simulate various link conditions and their effect on the spectral properties of the output quadrature processes are tabulated in Table 1. The Doppler spectrum (eq. A1-10) and auto and cross-correlation functions (real and imaginary parts of the equation A1-9) are plotted in Fig. 17 and 18 for all the cases described in Table 1. Some of the conclusions from this analysis are summarized below.

1. For symmetrical spectrum with no clock-offset, the cross-correlation function is zero for all τ (case 1,2,7,8).
2. For symmetrical spectrum, the clock-offset (average freq.) is obtained by averaging the imaginary part of the complex poles (case 3,3c,6,6c).
3. Slope of the cross-correlation function at zero by $[\dot{R}_{\alpha\beta}(o)]$ is obtained from the equation A1-11, and is equivalent to the average frequency of the spectrum, so the sign of $\dot{R}_{\alpha\beta}(o)$ can be computed from the average frequency of the process (1st moment).

4. For asymmetrical spectrum, the slope, $\dot{R}_{\alpha\beta}(o)$, could be zero. This results due to the fact that the average frequency of the asymmetrical spectrum due to the 'asymmetry' alone is equal and opposite in sign of the clock-offset. So the net average frequency of the spectrum is the sum of these two effects and is therefore zero (case 4,4c,9).
5. The auto correlation function of the quadrature processes after hard-clipping decays faster than the case of the unclipped signals.
6. Hard-clipping of the processes does not change the zero-crossings in auto and cross-correlation function.

Case no.	Pole locations $(-\tilde{k}_1, -\bar{k}_2)$	Spectrum symmetrical & asymmetrical	Average frequency	Cross-correlation $R_{\alpha\beta}(\tau)$ for all τ	Sense of $\hat{R}_{\alpha\beta}(o)$
1	-1+j,-1-j	symmetrical	zero	zero	zero
2	-1+2j,-1-2j	symmetrical	zero	zero	zero
3	-1,-1-j	symmetrical	(-ve)	non-zero	(-)ve
3c	-1,-1+j	symmetrical	(+)ve	non-zero	(+)ve
4	-2+2j,-1-j	asymmetrical	zero	non-zero	zero
4c	-2-2j,-1+j	asymmetrical	zero	non-zero	zero
5	-2,-1-j	asymmetrical	(-)ve	non-zero	(-)ve
5c	-2,-1+j	asymmetrical	(+)ve	non-zero	(+)ve
6	-2,-2-j	symmetrical	(-)ve	non-zero	(-)ve
6c	-2,-2+j	symmetrical	(+)ve	non-zero	(+)ve
7	-2+j,-2-j	symmetrical	zero	zero	zero
8	-2+2j,-2-2j	symmetrical	zero	zero	zero
9	-3+3j,-2-2j	asymmetrical	zero	non-zero	zero
10	-3+2j,-2-j	asymmetrical	(+)ve	non-zero	(+)ve

Table 1. Summary of the Spectral Analysis of Output of the Complex System for Different Pole Locations.

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Appendix 1

In this Appendix, a new concept of complex modeling is introduced. This complex modeling (for complex processes or orthogonal processes) is shown to be a special form of modeling bivariate processes. The complex representation of narrow-band processes has already been described in earlier reports. Here the state variable description of these processes is considered and its application to modeling the scatter portion of the channel is described.

In this complex state variable description [Baggeroer, 1970], a complex random process is generated by exciting a linear system having a complex state variable description with a complex white noise. The only assumptions made are on $\tilde{u}(t)$ and $\tilde{x}(T_0)$ where $\tilde{u}(t)$ is the complex white noise and $\tilde{x}(T_0)$ is the complex initial conditions of the linear system which could be assumed to have the following state variable description.

$$\frac{d}{dt}\tilde{x}(t) = \hat{F}(t)\tilde{x}(t) + \hat{G}(t)\hat{u}(t) \quad \text{[Linear State Equation]}$$

$$\tilde{z}(t) = \tilde{c}(t)\tilde{x}(t) \quad \text{[Linear Observation Equation]} \qquad \text{(A1-1)}$$

and $$\tilde{z}(t) = \alpha(t) + j\beta(t)$$

where all the coefficient matrices may be complex.

With the assumptions on $\tilde{u}(t)$ and $\tilde{x}(T_0)$, one can obtain the covariance function $k_{\tilde{z}(\tau)}$ of the output [Baggeroer, 1970]. From $k_{\tilde{z}(\tau)}$, the complex spectrum of $\tilde{z}(t)$, $s_z(\omega)$, can be obtained. It can be shown that the complex output $\tilde{z}(t) = \alpha(t) + j\beta(t)$ satisfies the conditions of narrow-band processes (orthogonal processes).

In this way, a complex process can be generated. It will be shown below that the different coefficient matrices could result in different complex models which will mimic the different channel conditions resulting due to clock-offset, misaligned antennas, varying fade rate and spectral shape of the channel. In the description below, an example (2nd order system) illustrates how these conditions of the channel can be simulated. This example is described in [Baggeroer, 1970], but its application in channel modeling is pointed out here. Finally, 1st-order system is considered which would be useful in simulating angular dependence function.

Derivation of the Channel Transfer Function

Let us consider a second-order system. In the steady-state, it corresponds to a system with two poles. The pole locations $-\tilde{k}_1$ and $-\tilde{k}_2$ need not be complex conjugates of one another. For this system, the state and observation equations are:

$$\frac{d}{dt}\begin{bmatrix}\tilde{x}_1(t)\\ \tilde{x}_2(t)\end{bmatrix} = \begin{bmatrix}0 & 1\\ -\tilde{k}_1\tilde{k}_2 & -(\tilde{k}_1+\tilde{k}_2)\end{bmatrix}\begin{bmatrix}\tilde{x}_1(t)\\ \tilde{x}_2(t)\end{bmatrix} + \begin{bmatrix}0\\ 1\end{bmatrix}\tilde{u}(t)$$

$$\text{and } \tilde{z}(t) = [1:0]\begin{bmatrix}x_1(t)\\ x_2(t)\end{bmatrix}$$

By simple manipulations, it can be shown that the above equation corresponds to

$$\ddot{\tilde{z}}(t) = -\tilde{k}_1\tilde{k}_2\,\tilde{z}(t) - (\tilde{k}_1+\tilde{k}_2)\,\dot{\tilde{z}}(t) + \tilde{u}(t) \qquad \text{(A1-2)}$$

Let $\tilde{z}(t) = \alpha(t) + j\beta(t)$

$$\begin{aligned} \tilde{k}_1 &= a+jb \\ \tilde{k}_2 &= c+jd \\ A &= ac-bd \\ B &= bc+ad \\ E &= a+c \\ F &= b+d \end{aligned} \tag{A1-3}$$

The above equation (A1-2) can be rewritten as:

$$\ddot{\alpha}(t) + j\ddot{\beta}(t) = -(E+jF)[\dot{\alpha}(t) + j\dot{\beta}(t)] - [A+jB]\cdot[\alpha(t) + j\beta(t)] + U_1(t)+jU_2(t) \tag{A1-4}$$

Separating real and imaginary parts in Eq. (A1-4), one can obtain

$$\begin{aligned} \ddot{\alpha}(t) + E\dot{\alpha}(t) - F\dot{\beta}(t) + A\alpha(t) - B\beta(t) &= U_1(t) \\ \ddot{\beta}(t) + E\dot{\beta}(t) + F\dot{\alpha}(t) + B\alpha(t) + A\beta(t) &= U_2(t) \end{aligned} \tag{A1-5}$$

Equation (A1-4) can be written in transfer function form. Let us assume that $U_1(t)$, $U_2(t)$, $\alpha(t)$, $\beta(t)$ are general input-output of a bivariate system, such that their Laplace Transforms can be taken. Then by simple manipulations, one can show that

$$\alpha(s) = \frac{(s^2+ES+A)}{(s^2+ES+A)^2+(FS+B)^2} U_1(s) + \frac{(FS+B)}{(s^2+ES+A)^2+(FS+B)^2} U_2(s)$$

and (A1-6)

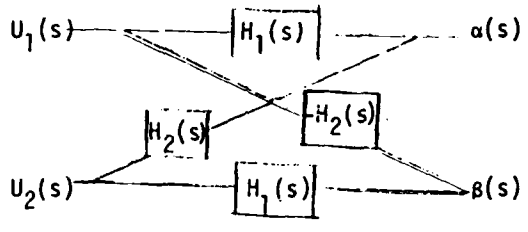
$$\beta(s) = \frac{s^2+ES+A}{(s^2+ES+A)^2+(FS+B)^2} U_2(s) - \frac{(FS+B)}{(s^2+ES+A)^2+(FS+B)^2} U_1(s)$$

$$\text{If } H_1(s) = \frac{s^2+ES+A}{(s^2+ES+A)^2+(FS+B)^2} \quad \text{and } H_2(s) = \frac{FS+B}{(s^2+ES+A)^2+(FS+B)^2} \tag{A1-7}$$

then, equation (A1-6) can be written as:

$$\alpha(s) = H_1(s)U_1(s) + H_2(s)U_2(s)$$
$$\text{and} \quad \beta(s) = H_1(s)U_2(s) - H_2(s)U_1(s) \tag{A1-8}$$

Equation (A1-8) can be written in block-diagram form as:



In the above block diagram, it can be observed that the forward transfer function $H_1(s)$ in both the paths are the same and the transfer function in the cross-paths $[H_2(s)]$ are equal but of opposite sign. The author points out here that this is the condition for modeling complex processes (orthogonal processes) in quadrature form.

If, in equations (A1-6) and (A1-8), B=0 and F=0, then $H_2(s)$ is zero. For this condition there is no cross-coupling between two quadrature components $\alpha(t)$ and $\beta(t)$, and these two processes are uncorrelated. As discussed earlier, zero correlation implies symmetrical spectrum with no clock-offset. If B=0 and F=0, then a=c and b=-d e.g., both the poles are mirror images of one another about σ-axis in $s(=\sigma+j\omega)$ plane.

For non-zero, B and F constants, $H_2(s)$ is not zero and $\alpha(t)$ and $\beta(t)$ processes are correlated. Since B and F are functions of the poles of the system (k_1,k_2), that implies that the pole position determines the shape of the power spectral density of the complex process. Equation (A1-5) can easily be simulated on an analog computer. By varying pole locations $(\tilde{k}_1,\tilde{k}_2)$, one can obtain different spectrums. Also note that the differential equations involving $\alpha(t)$ and $\beta(t)$ in Eq. (A1-5) are coupled equations. So 'coupled' systems (e.g. non-ideal transformer) can be analyzed by this complex or phasor analysis.

The covariance function $K_{\tilde{z}}(t,t)$ of the output is given by [Baggeroer, 1970]: (P is the input noise power).

$$k_{\tilde{z}}(\tau) = \begin{cases} \dfrac{P}{(\tilde{k}_2-\tilde{k}_1)^*}\left[\left(\tilde{k}_2^*\, e^{\tilde{k}_1^*\tau}-\tilde{k}_1^*\, e^{\tilde{k}_2^*\tau}\right) + j\,\dfrac{\mathrm{Im}[\tilde{k}_1\tilde{k}_2]}{\mathrm{Re}[\tilde{k}_1+\tilde{k}_2]}\left(e^{\tilde{k}_1^*\tau}-e^{\tilde{k}_2^*\tau}\right)\right] & \tau < 0 \\ \dfrac{P}{(\tilde{k}_2-\tilde{k}_1)}\left[\left(\tilde{k}_2\, e^{-\tilde{k}_1\tau}-\tilde{k}_1\, e^{-\tilde{k}_2\tau}\right) - j\,\dfrac{\mathrm{Im}[\tilde{k}_1\tilde{k}_2]}{\mathrm{Re}[\tilde{k}_1+\tilde{k}_2]}\left(e^{-\tilde{k}_1\tau}-e^{-\tilde{k}_2\tau}\right)\right] & \tau > 0 \end{cases} \qquad \text{(A1-9)}$$

From e.g. (A-9), one can compute $s_{\tilde{z}}(\omega)$ as:

Let

$$\tilde{A}_1 = \frac{\tilde{k}_2+\tilde{k}_1^*}{(\tilde{k}_2-\tilde{k}_1)} \cdot \frac{\mathrm{Re}[\tilde{k}_2]}{\mathrm{Re}[\tilde{k}_1+\tilde{k}_2]}$$

$$\tilde{A}_2 = -\frac{k_1+k_2^*}{(\tilde{k}_2-\tilde{k}_1)} \cdot \frac{\mathrm{Re}[\tilde{k}_1]}{\mathrm{Re}[\tilde{k}_1+\tilde{k}_2]}$$

then

$$S_{\tilde{z}}(\omega) = 2P\left[\frac{Re[\tilde{A}_1]Re[\tilde{k}_1]+Im[\tilde{A}_1](\omega+Im[\tilde{k}_1])}{Re^2[\tilde{k}_1]+[\omega+Im(\tilde{k}_1)]^2} + \frac{Re[\tilde{A}_2]Re[\tilde{k}_2]+Im[\tilde{A}_2](\omega+Im[\tilde{k}_2])}{Re^2[\tilde{k}_2]+[\omega+Im(\tilde{k}_2)]^2}\right] \quad \text{(A1-10)}$$

From e.g. (A1-9) one can obtain:

$$\dot{R}(0) = -j\left[\frac{bc+ad}{a+c}\right] = -j\frac{B}{E} \quad \text{(A1-11)}$$

and

$$\ddot{R}(0) = -\frac{a(c^2+d^2)+c(a^2+b^2)}{a+c} = -\left(A+\frac{BF}{E}\right) \quad \text{(A1-12)}$$

First-order Complex System:

The equations that describe the 1st-order system with one pole $(-\tilde{k})$ are:

$$\frac{d\tilde{x}(t)}{dt} = -\tilde{k}\,\tilde{x}(t) + \tilde{u}(t) \qquad \text{(state equation)} \quad \text{(A1-13)}$$

and $$\tilde{z}(t) = \tilde{x}(t) \qquad \text{(observation equation)}$$

Following the steps similar to 2nd-order system, one can obtain by letting

$$\tilde{k} = a+jb \quad \text{(A1-14)}$$

and $$\tilde{z}(t) = \alpha(t) + j\beta(t)$$

that

$$H_1(s) = \frac{s+a}{(s+a)^2+b^2} \quad \text{and} \quad H_2(s) = \frac{b}{(s+a)^2+b^2} \tag{A1-15}$$

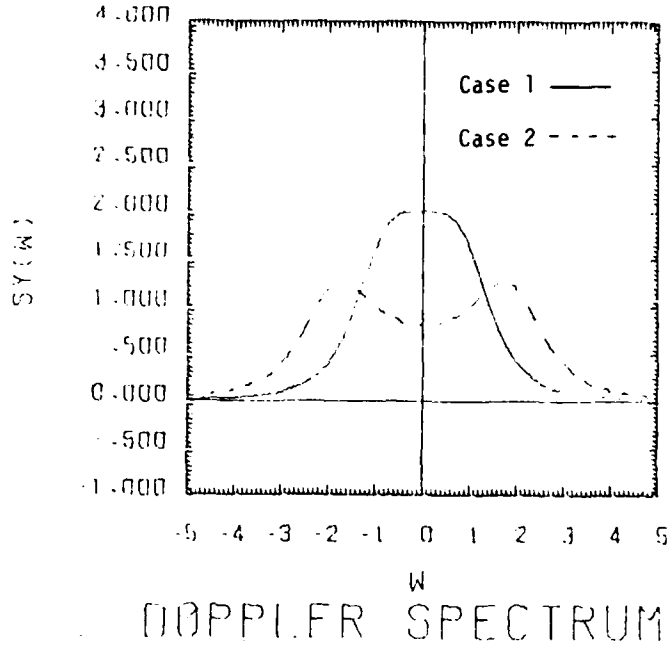
Similar to equations (A1-9) and (A1-10) one obtains [Baggeroer, 1970]

$$k_{\tilde{z}}(\tau) = P\, e^{-Re[\tilde{k}]|\tau|}\, e^{-jIm[\tilde{k}]\tau} \tag{A1-16}$$

and

$$s_{\tilde{z}}(\omega) = \frac{2Re[\tilde{k}]P}{(\omega-Im[k])^2+Re[k]^2} \tag{A1-17}$$

The auto and cross spectra of $\alpha(t)$ and $\beta(t)$ can easily be found in terms of even and odd parts of $s_{\tilde{z}}(\omega)$. Note that the net effect of allowing a complex gain in e.g. (A1-13) is that the spectrum has a frequency shift equal to the imaginary part of the gain.


Case 1
Case 2
4.000
3.500
3.000
2.500
2.000
1.500
1.000
.500
0.000
-.500
-1.000
-5 -4 -3 -2 -1 0 1 2 3 4 5
W
DOPPLER SPECTRUM

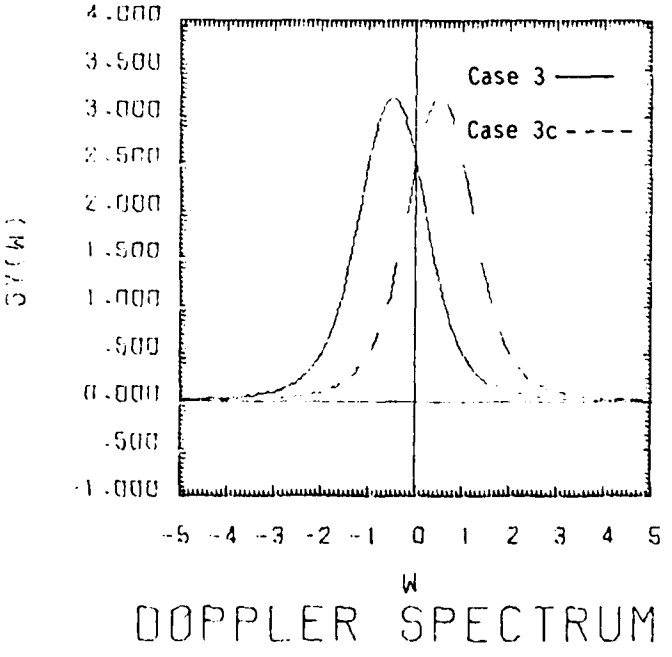
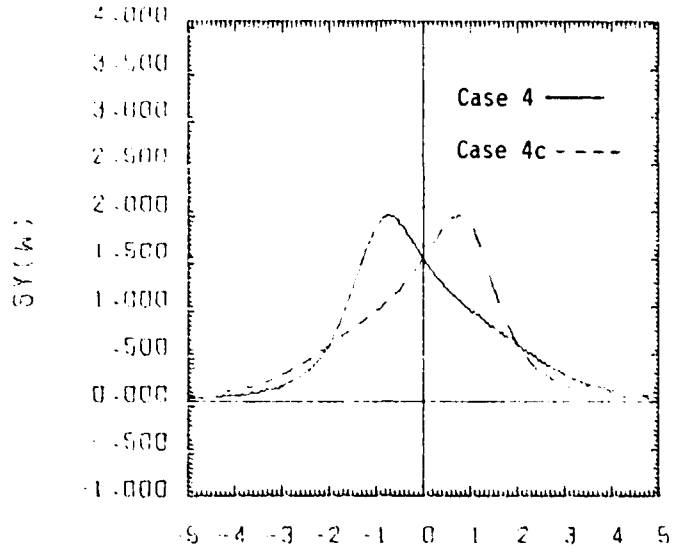
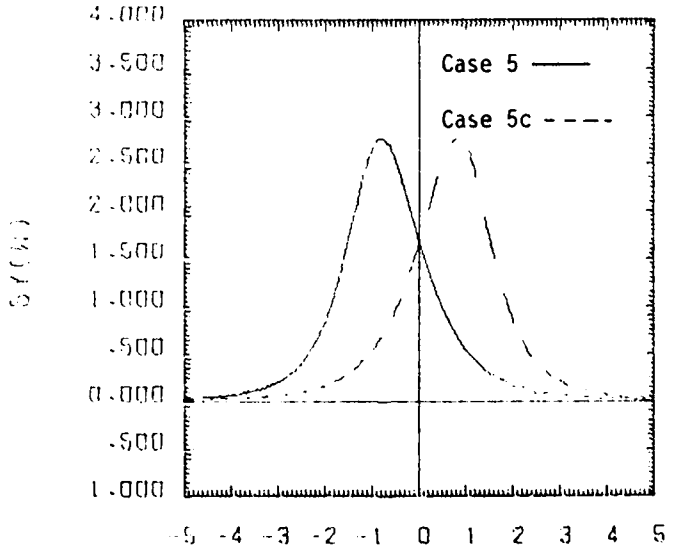

Case 3
Case 3c
4.000
3.500
3.000
2.500
2.000
1.500
1.000
.500
0.000
-.500
-1.000
-5 -4 -3 -2 -1 0 1 2 3 4 5
W
DOPPLER SPECTRUM

Fig. 17a

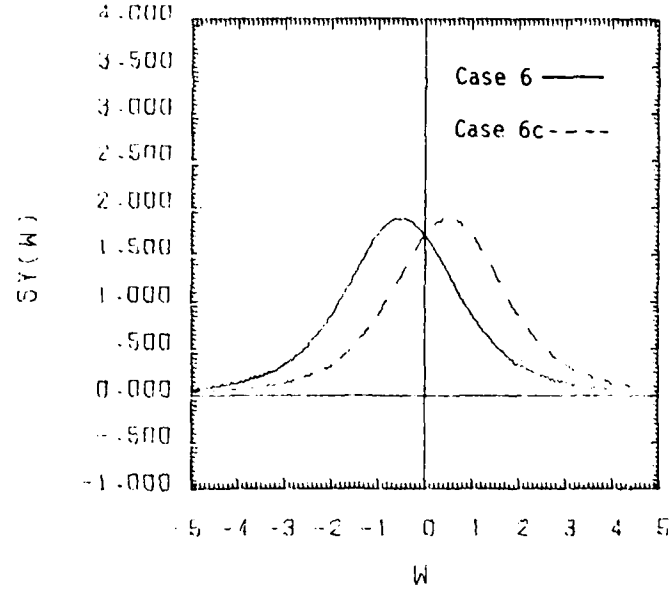


DOPPLER SPECTRUM

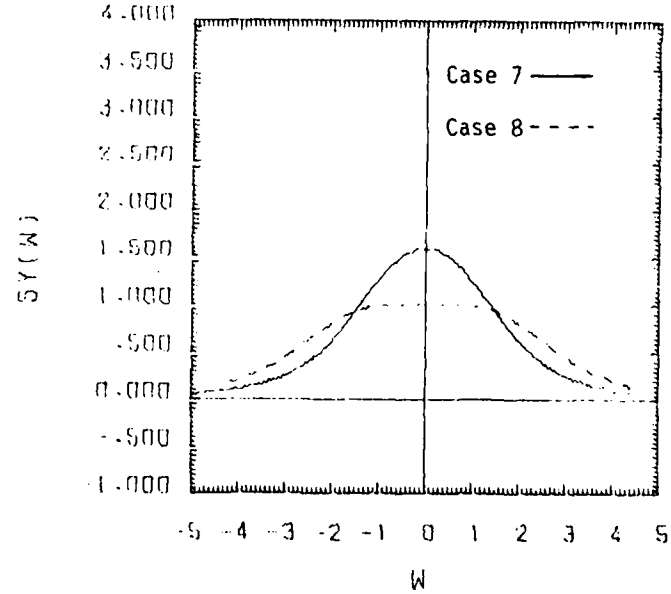


DOPPLER SPECTRUM

Fig. 17b



DOPPLER SPECTRUM



DOPPLER SPECTRUM

Fig. 17c

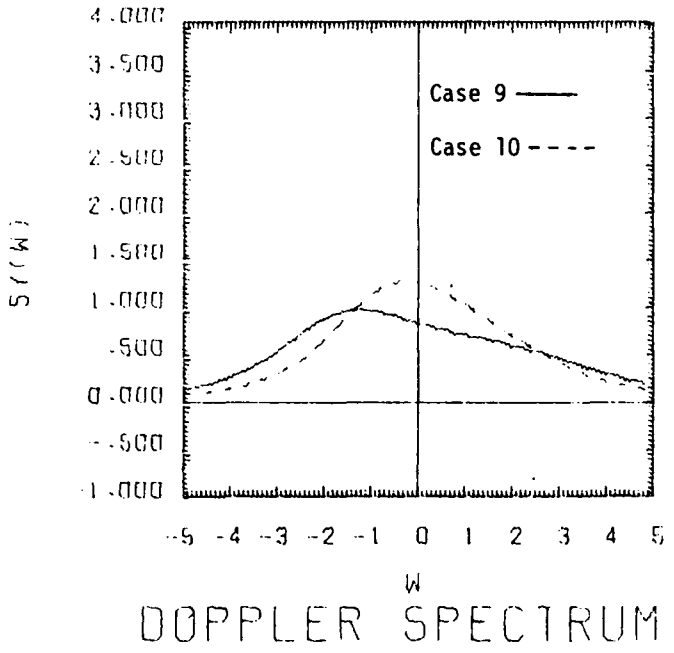
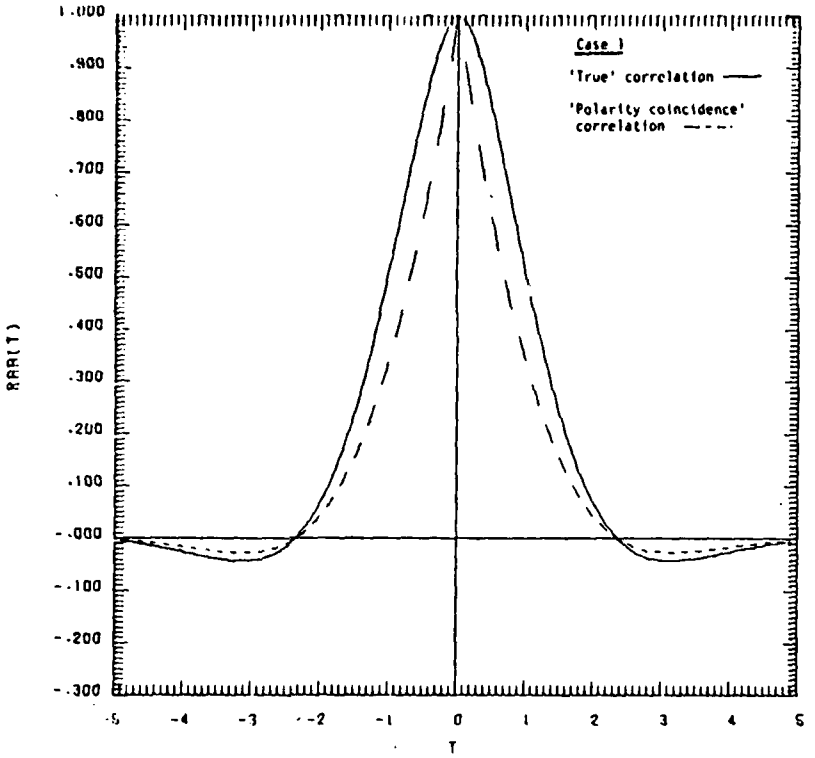
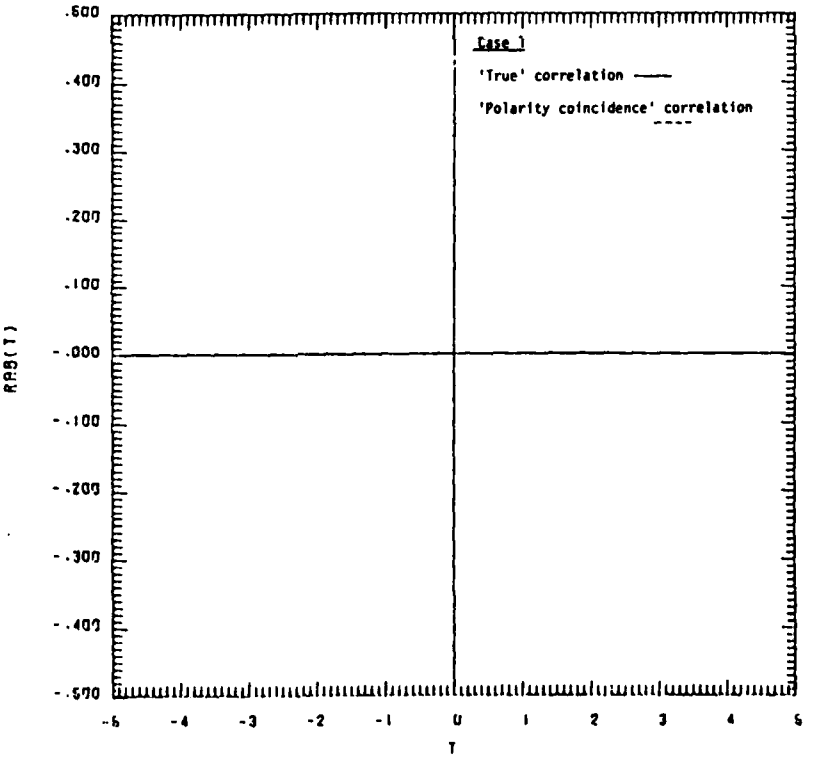

4.000
3.500
3.000
2.500
2.000
1.500
1.000
.500
0.000
-.500
-1.000
S(W)
Case 9
Case 10
-5 -4 -3 -2 -1 0 1 2 3 4 5
W
DOPPLER SPECTRUM

Fig. 17d



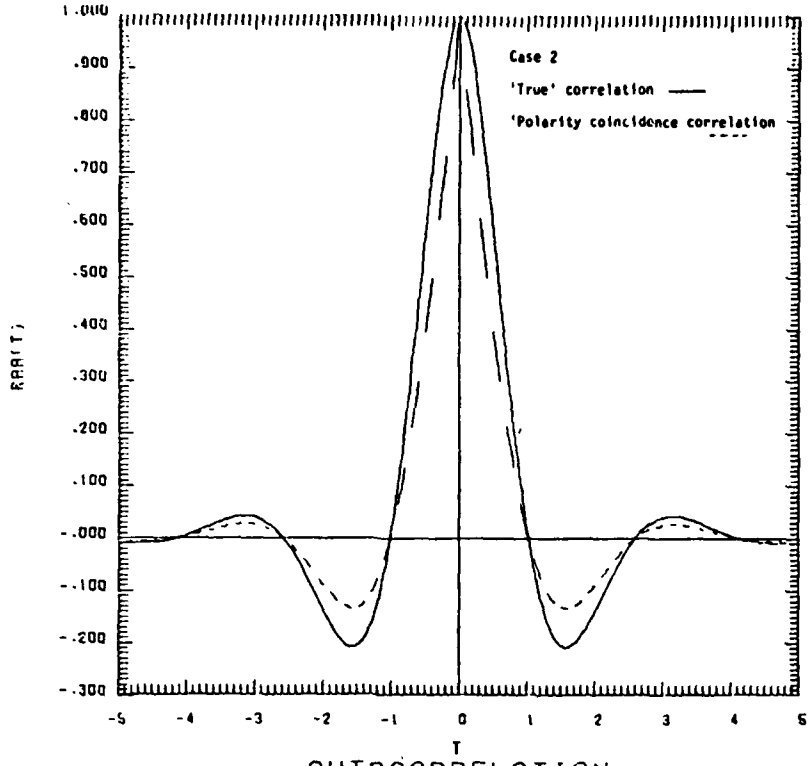
AUTOCORRELATION

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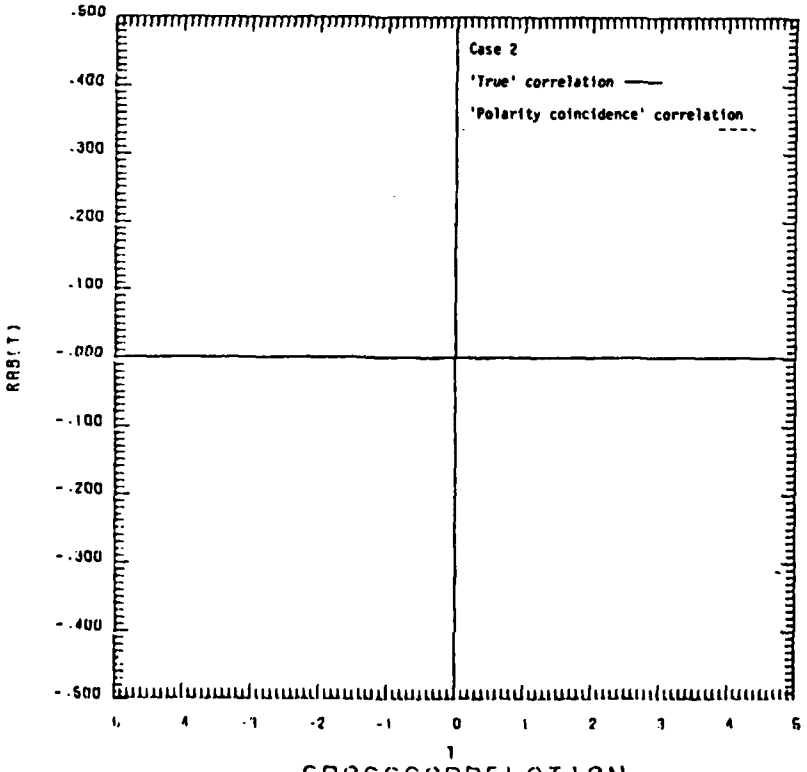
CROSSCORRELATION

Fig. 18a



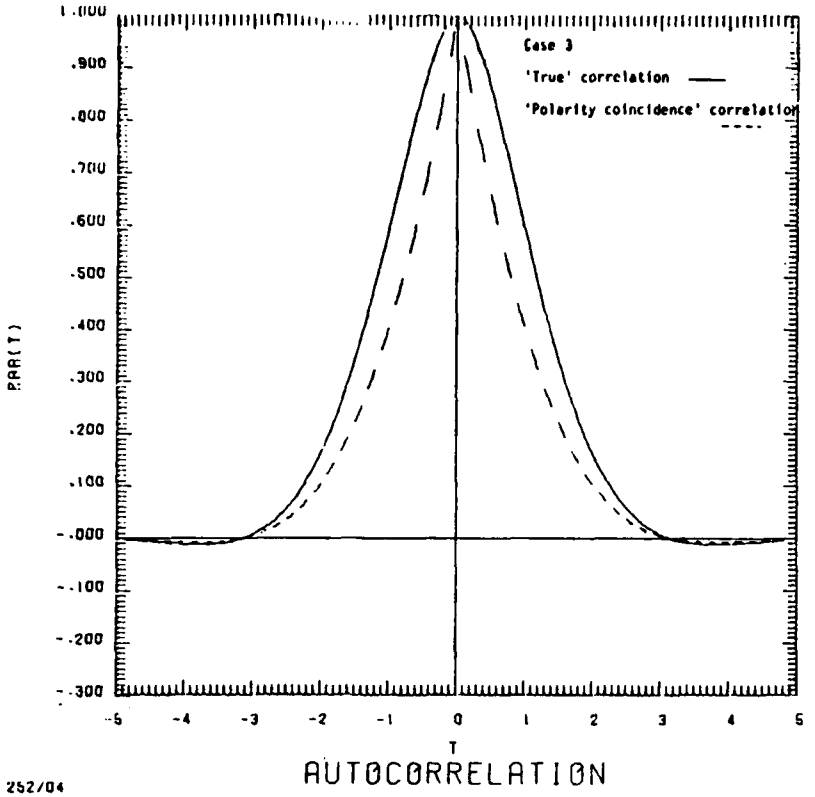
AUTOCORRELATION

247/04



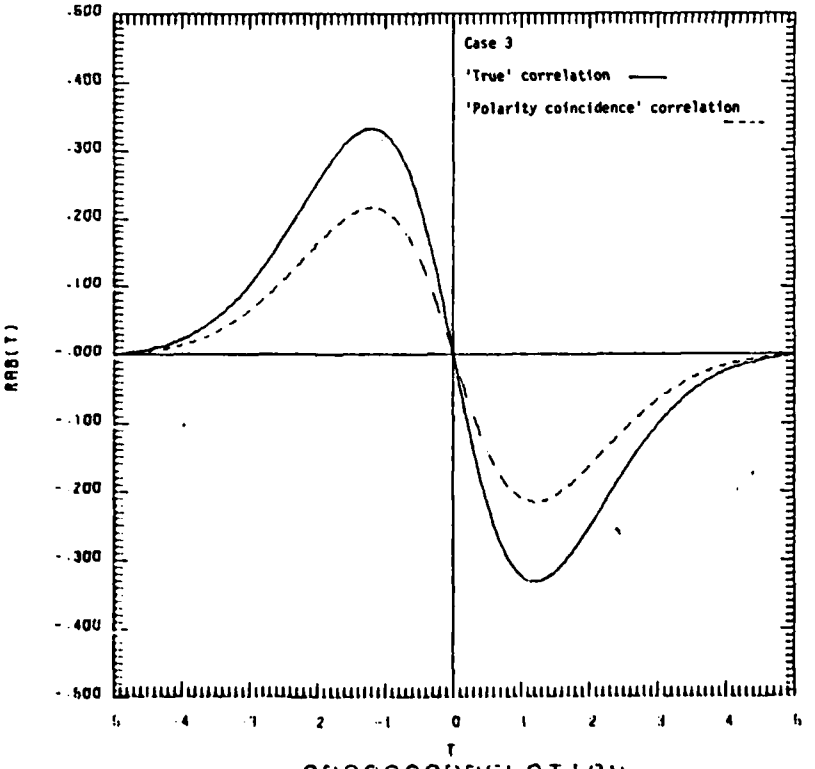
CROSSCORRELATION

Fig. 18b



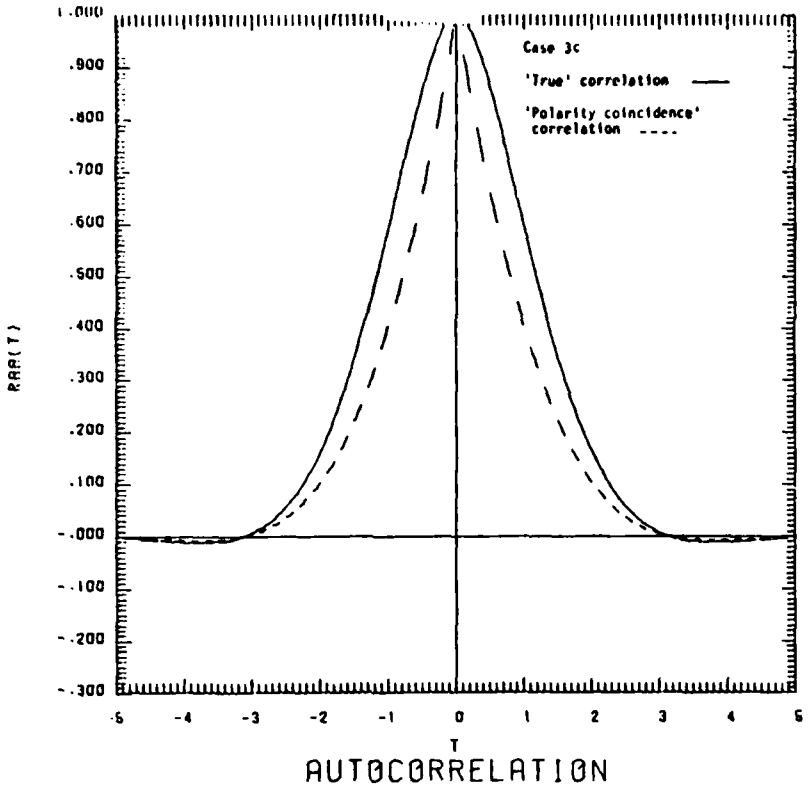
AUTOCORRELATION

252/04

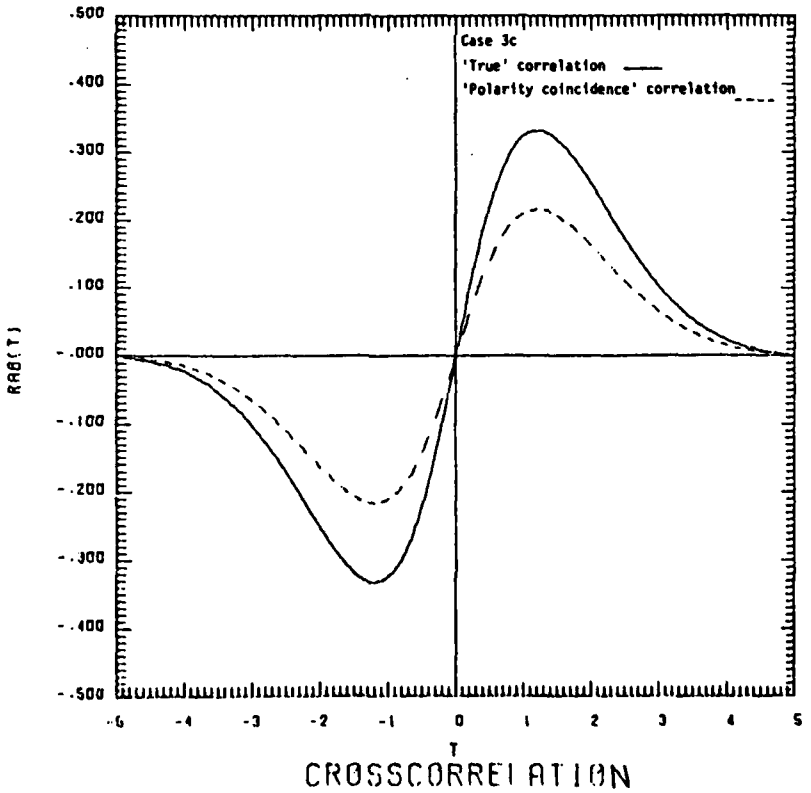


CROSSCORRELATION

Fig. 18c

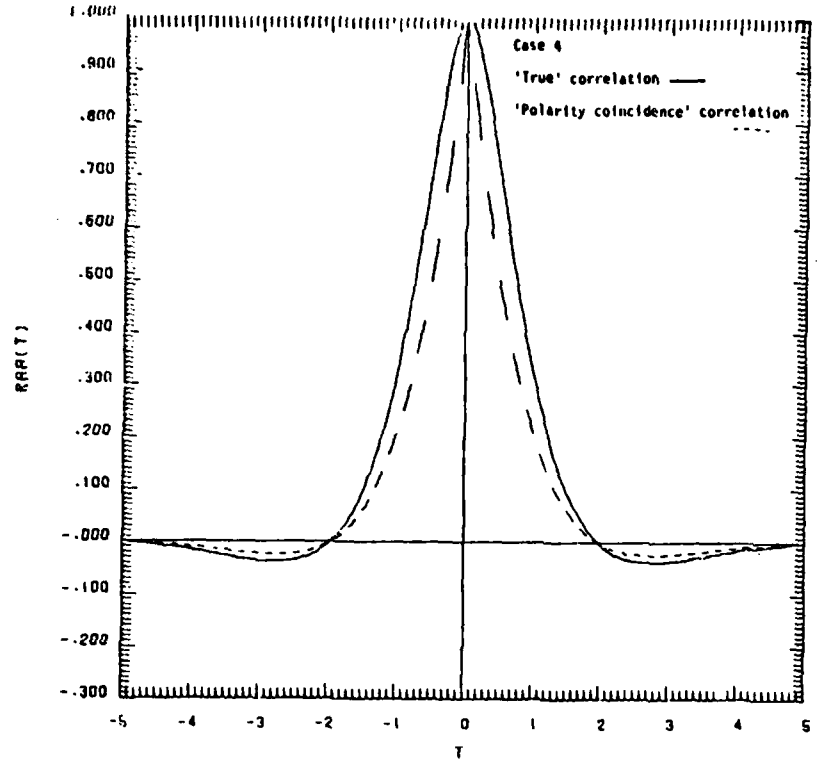


AUTOCORRELATION



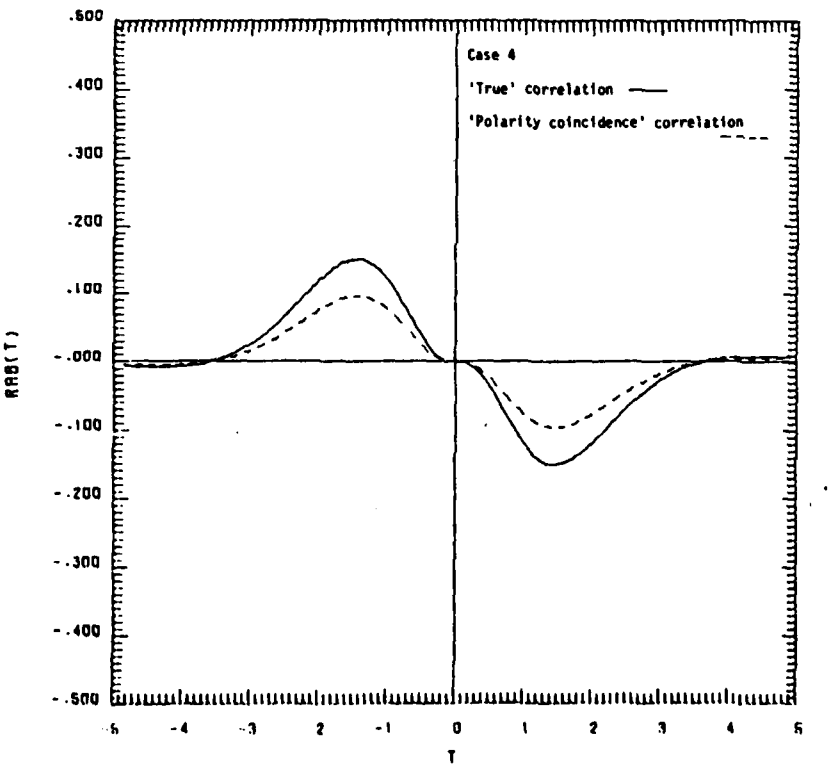
CROSSCORRELATION

Fig. 18d



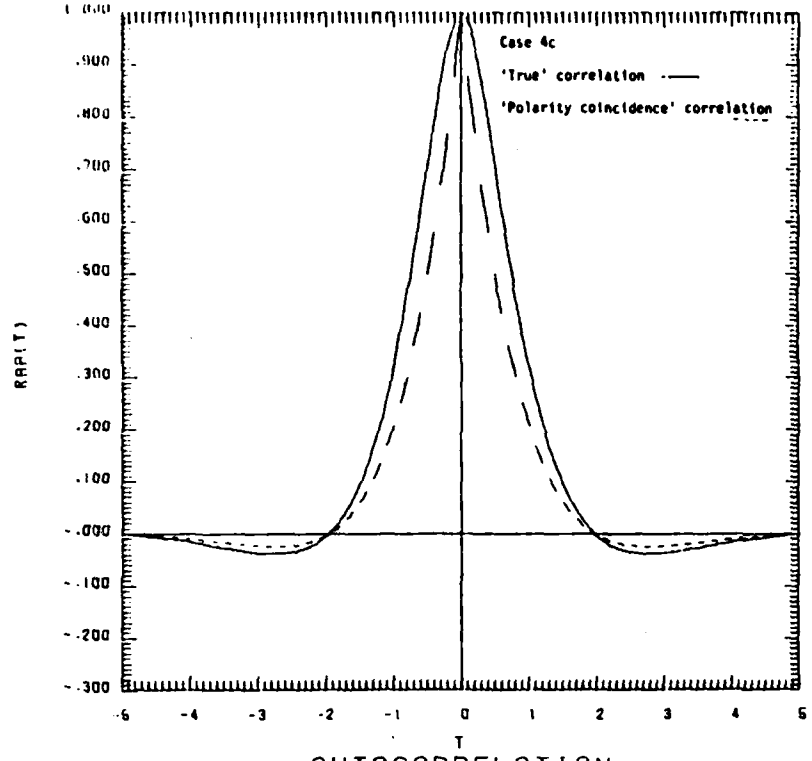
AUTOCORRELATION

.267/04

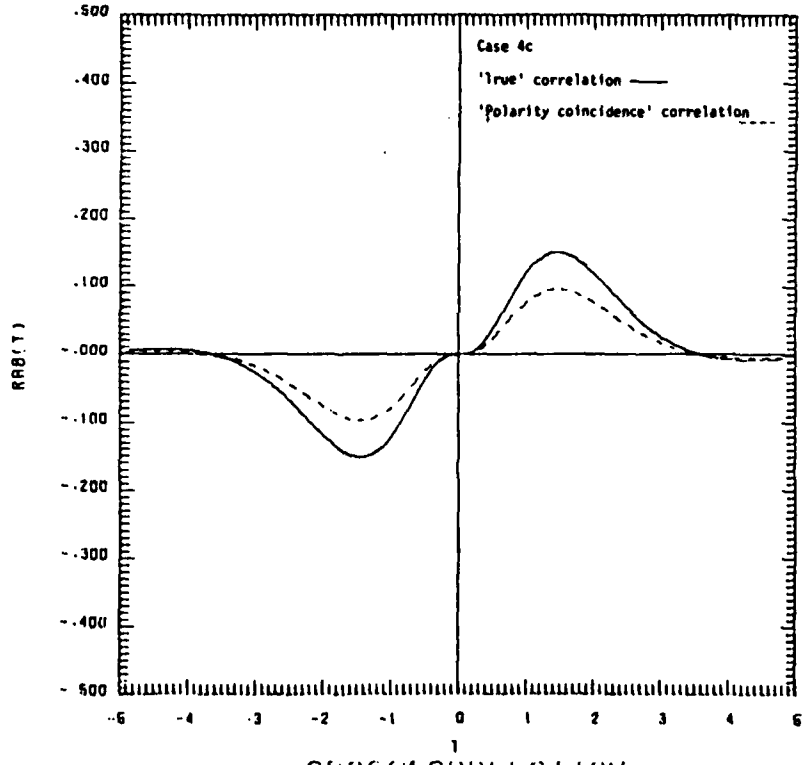


CROSSCORRELATION

Fig: 18e

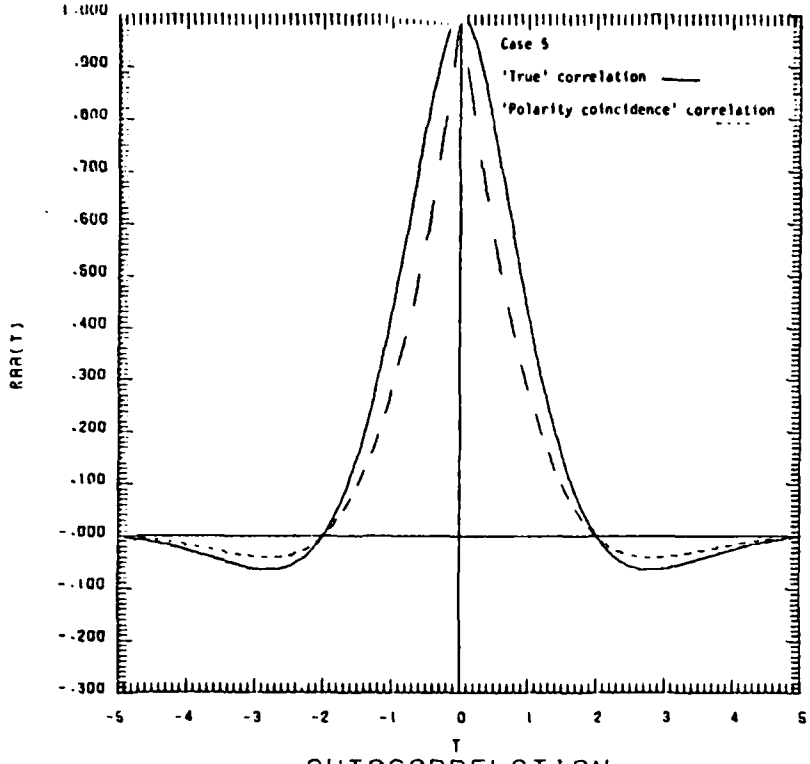


AUTOCORRELATION



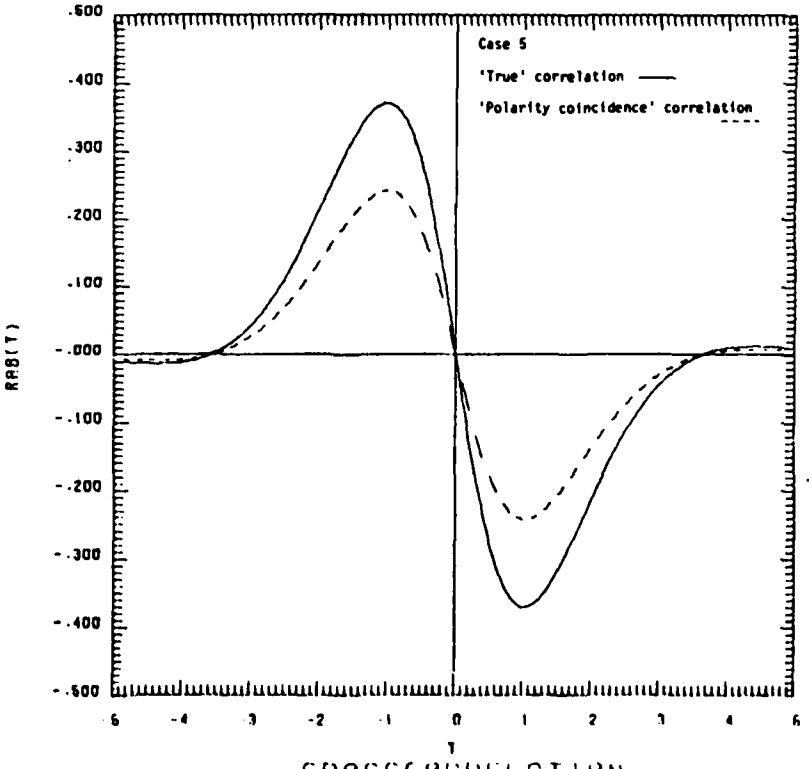
CROSSCORRELATION

Fig. 18f



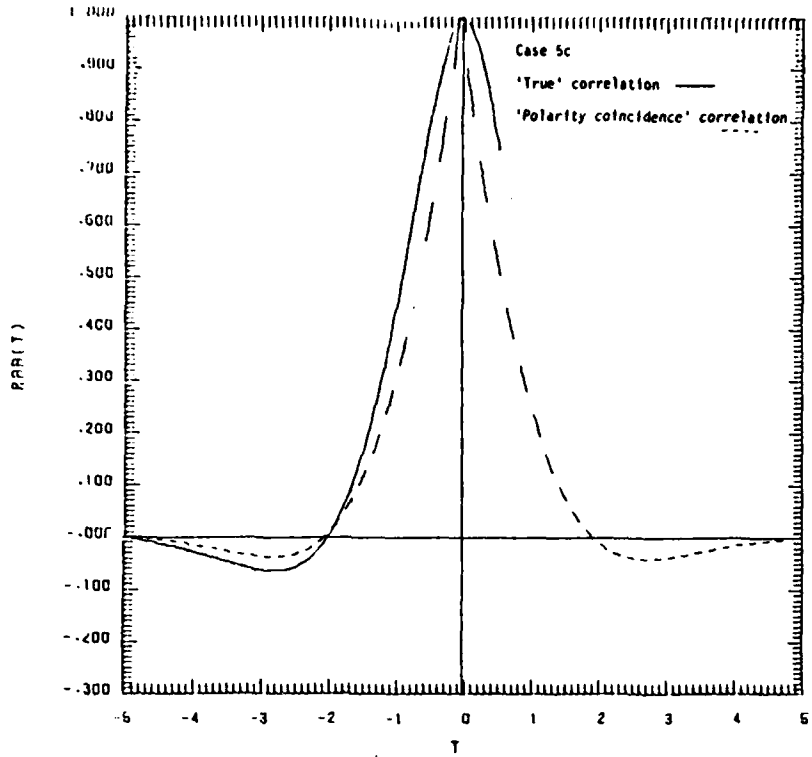
AUTOCORRELATION

497/04



CROSSCORRELATION

Fig. 18g


Case 5c
'True' correlation
'Polarity coincidence' correlation
RAA(T)
T
AUTOCORRELATION

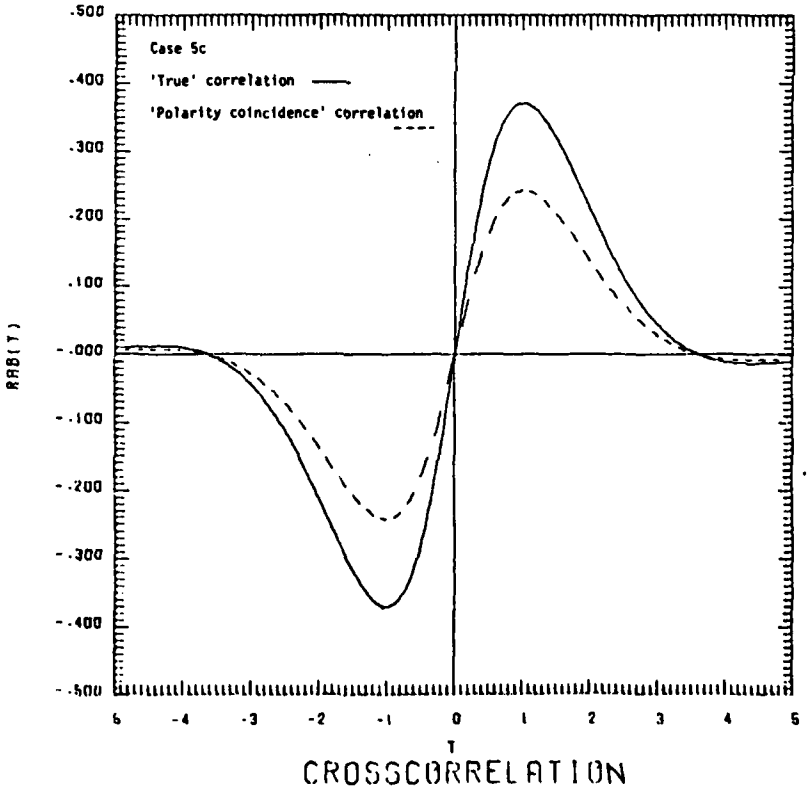
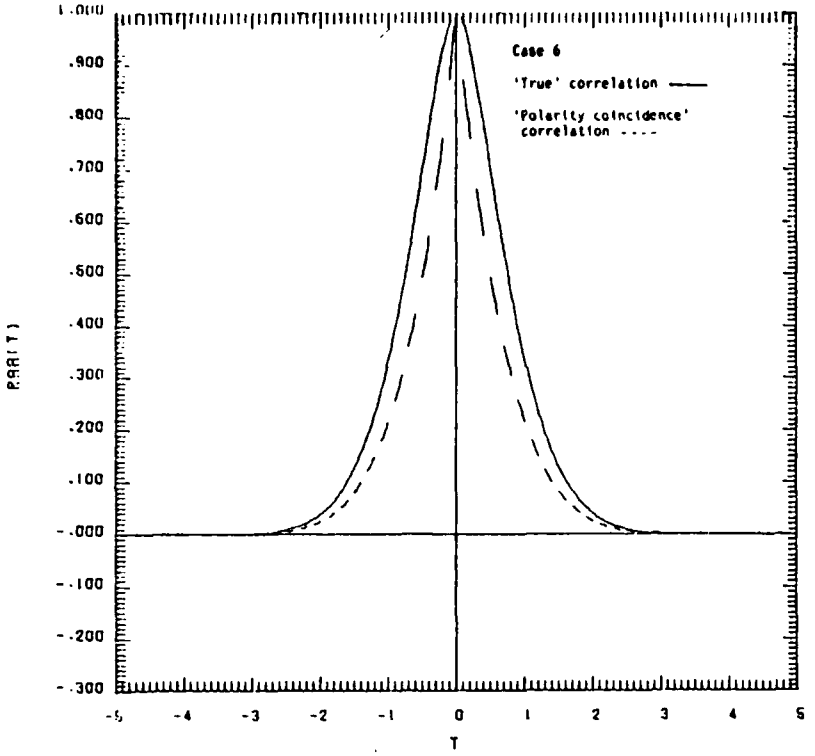
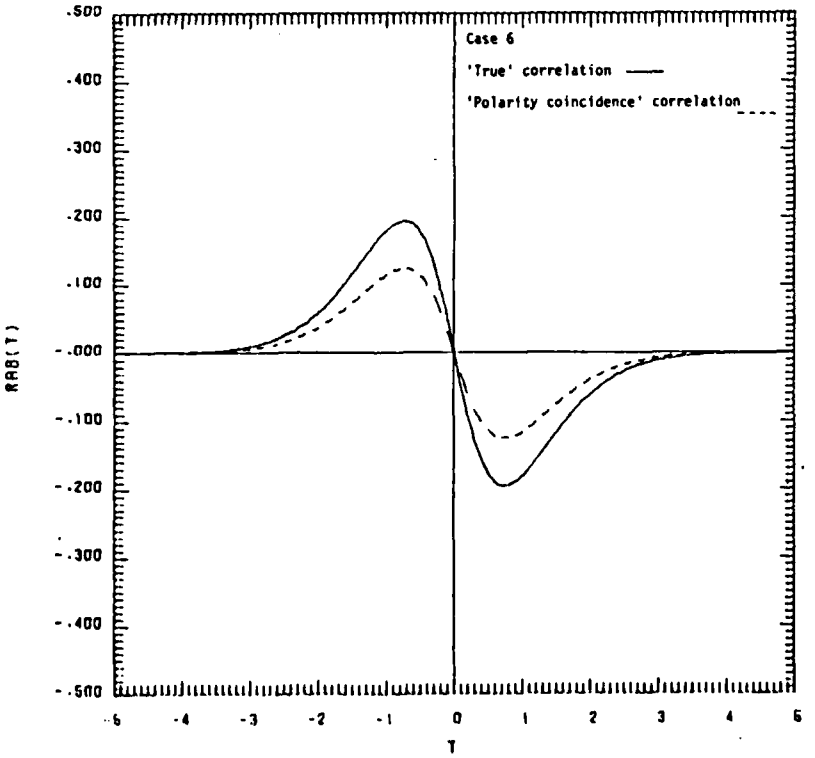

Case 5c
'True' correlation
'Polarity coincidence' correlation
RAB(T)
T
CROSSCORRELATION

Fig. 18h

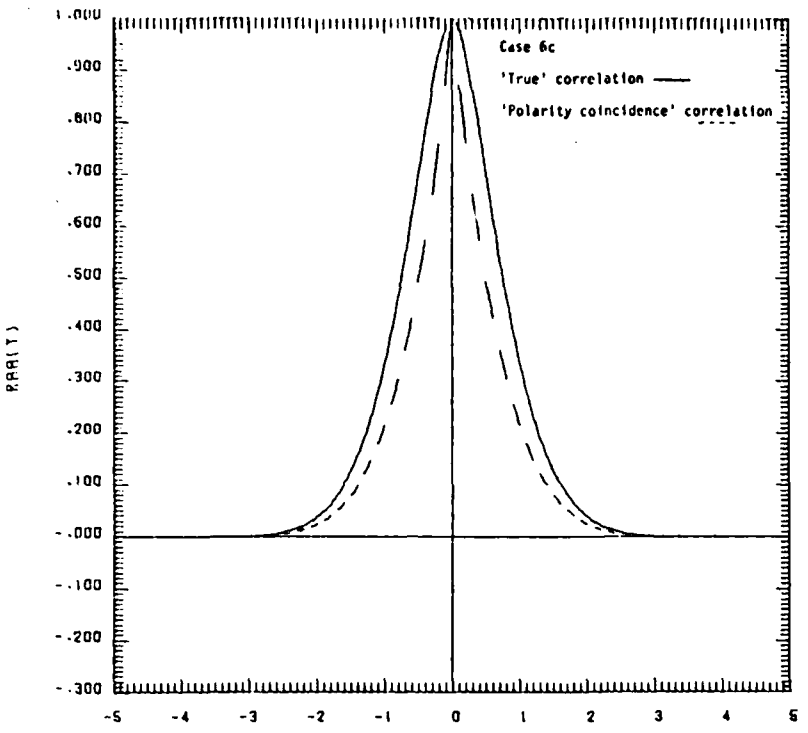


AUTOCORRELATION

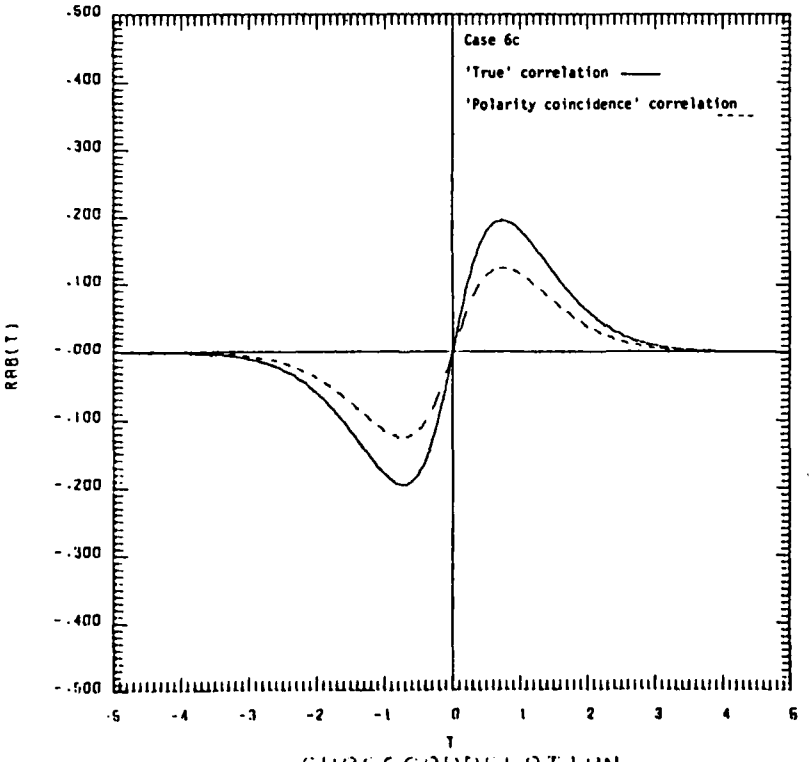


CROSSCORRELATION

Fig. 18i

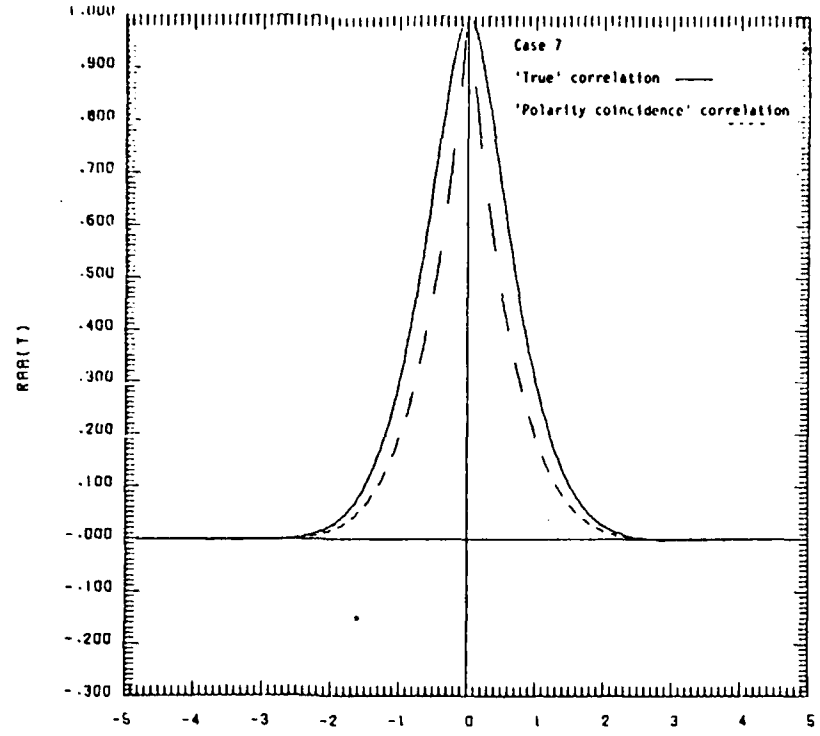


AUTOCORRELATION



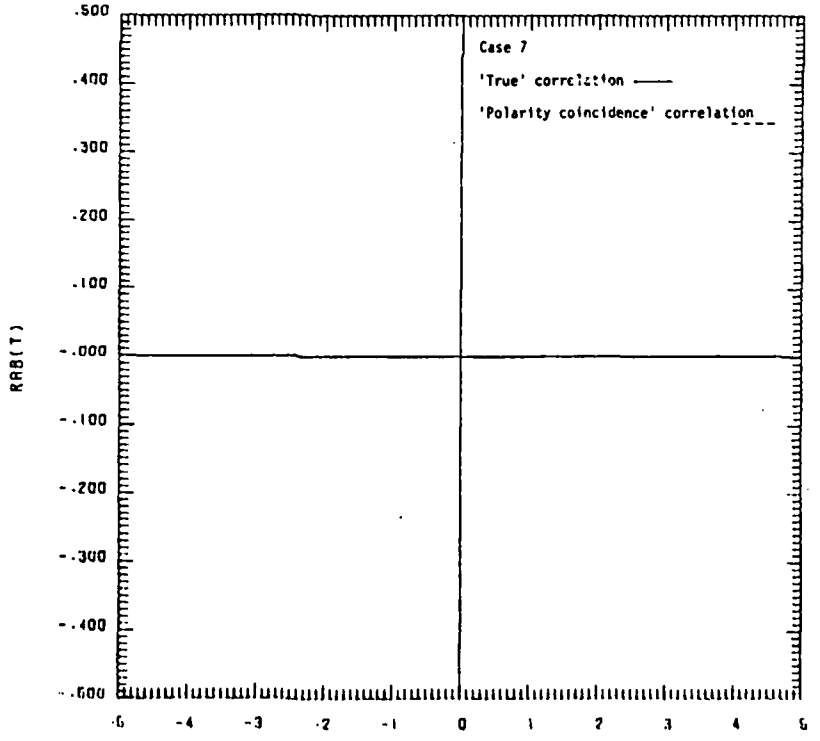
CROSSCORRELATION

Fig. 18j



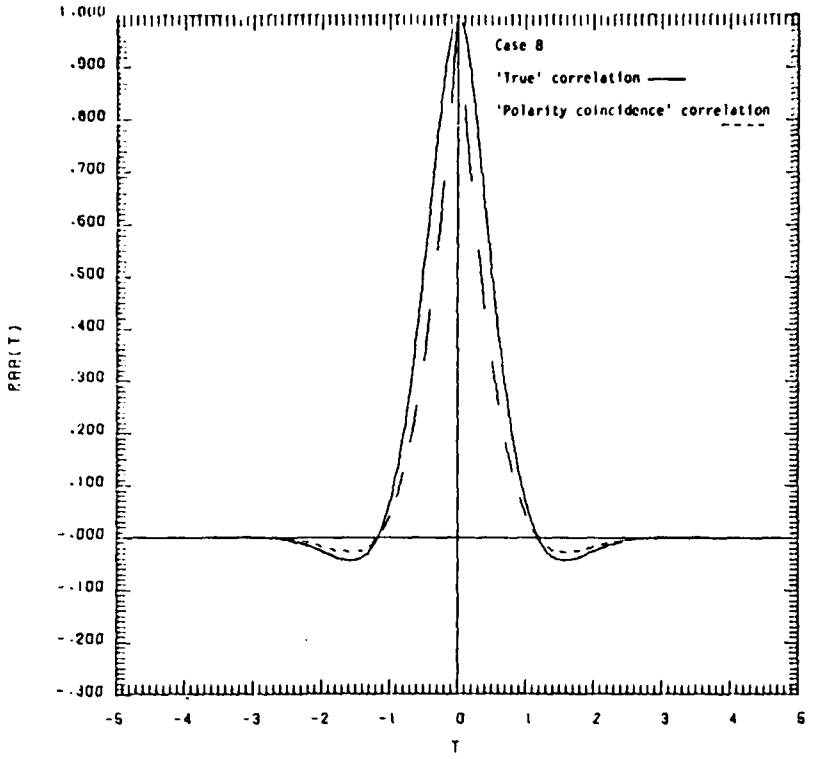
AUTOCORRELATION

S047/04

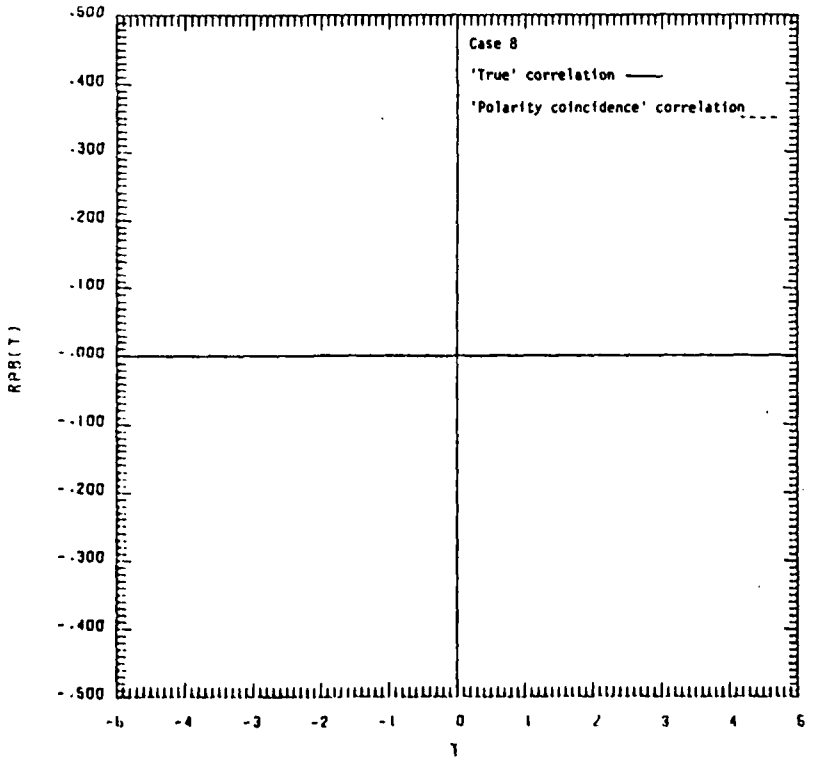


CROSSCORRELATION

Fig. 18k

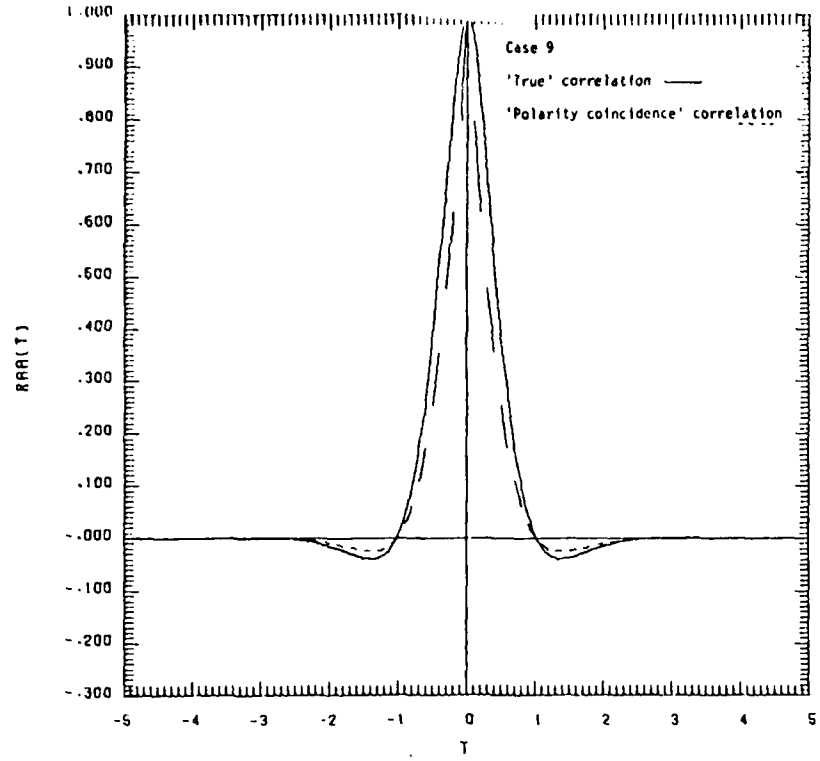


AUTOCORRELATION



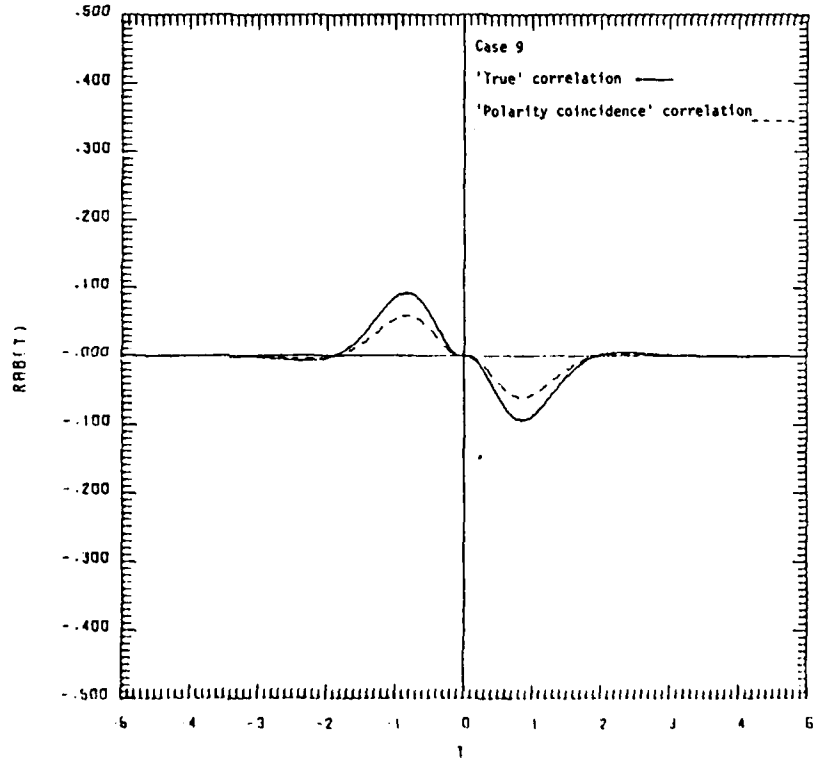
CROSSCORRELATION

Fig. 181



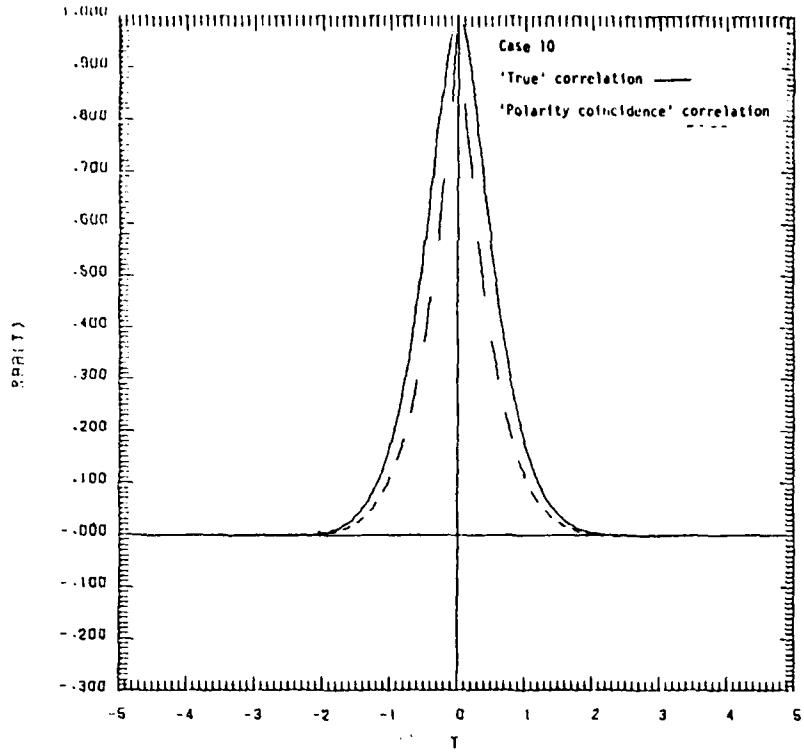
AUTOCORRELATION

5075/04

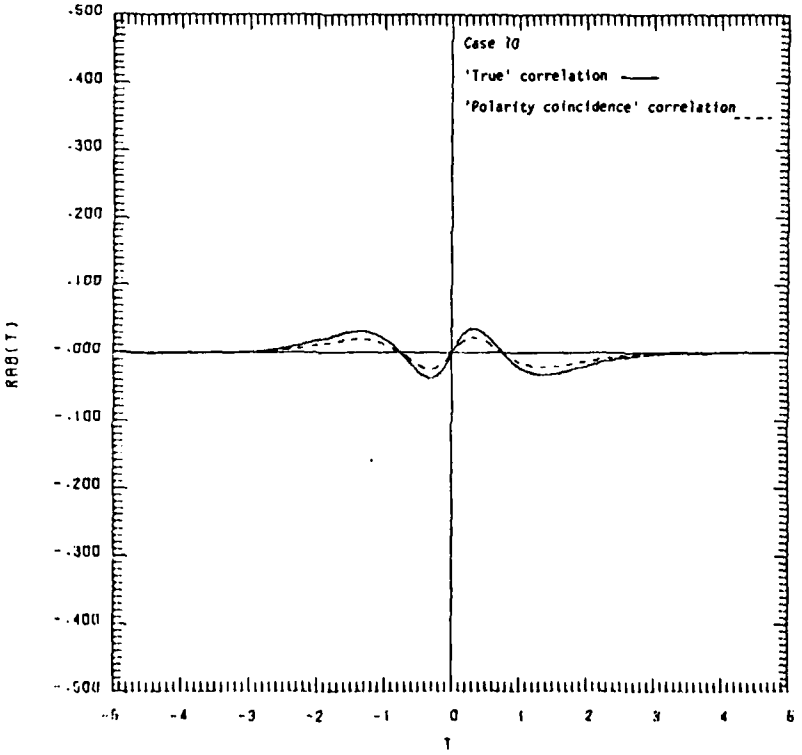


CROSSCORRELATION

Fig. 18m



AUTOCORRELATION



CROSSCORRELATION

Fig. 18n